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# DRAFT

# ISSUE-ORIENTED SITE TECHNICAL POSITION (ISTP)

# FOR

# SALT REPOSITORY PROJECT (SRP)

# GULF COAST SALT DOME SITES

SEPTEMBER 1984


DIVISION OF WASTE MANAGEMENT

U.S. NUCLEAR REGULATORY COMMISSION

# DRAFT
# SITE TECHNICAL POSITION
# SALT REPOSITORY PROJECT (SRP)
# GULF COAST DOMES SITES

## Purpose

In reviewing a license application for a high-level waste geologic repository, the NRC staff will assess compliance with the numerical performance objectives and the qualitative siting and design criteria of 10 CFR Part 60, Subpart E. Staff positions will be based on independent assessments of data and data analyses that are presented in the license application to address the technical questions (licensing issues) that must be addressed to determine site and design suitability in terms of 10 CFR Part 60.

The general purpose of the Issue-oriented Site Technical Positions (ISTPs) developed by the staff is to identify and present the rationales for the licensing issues that the staff will address, as a minimum, for each site prior to licensing. Because the numerical performance objectives are a key part of the technical criteria of 10 CFR Part 60, Subpart E, the staff's approach has been to develop these licensing issues in a manner that clearly relates to performance of the geologic repository system and its subsystem elements.

The ISTPs are being developed at this early stage of the prelicensing consultation and guidance process for several reasons:

1. The issues presented will serve as a set of benchmarks against which the NRC staff can independently review the relevance and completeness of issues identified by the Department of Energy (DOE) in the Site Characterization Plans (SCPs).

2. The issues provide a systematic structure for staff guidance to DOE and for tracking the progress toward addressing staff concerns about licensing issues throughout the site characterization process. The intent is to establish a tracking system which ties together all of the various documents that are pertinent to a given issue.

3. Finally, the issues provide a systematic and logical framework for NRC staff to organize the ultimate task of assessing geologic repository performance and compliance with criteria of 10 CFR Part 60.

The ISTPs are being released at this time in draft form for review and comment by DOE, States, Indian tribes, and the interested public. The NRC staff will consider comments and develop a revised ISTP based in part on this input.

Background

At the time of licensing for a geologic repository, DOE has the responsibility to present and defend a licensing assessment of the geologic repository system and its components as required by 10 CFR Part 60. The first NRC licensing action, which site characterization addresses, is the decision on Construction Authorization. To receive an authorization to construct the geologic repository, DOE must demonstrate through the Safety Analysis Report (10CFR60.21) "that there is reasonable assurance that the types and amounts of radioactive materials described in the application can be received, possessed and disposed of in a geologic repository operations area of the design proposed without unreasonable risk to the health and safety of the public" (10CFR60.31(a)).

As part of its licensing responsibility, the NRC staff will review DOE's description of the proposed geologic repository (10CFR60.31)(a)(1)) and DOE's assessment of the performance of the site and design with respect to technical criteria contained in Subpart E (10CFR60.31(a)(2)). Subpart E technical criteria include both numerical performance objectives and qualitative site and design criteria that apply to any proposed geologic repository, regardless of geologic medium.

Although submission of a license application is not anticipated for several years, the technical investigations needed to characterize a geologic repository, and development of appropriate site-specific designs for engineered components, are complex activities; many aspects require long lead times. To assure that the data and data analyses which are necessary and sufficient to support a license application are developed in DOE's site characterization program, it is essential that at an early time DOE identify the complete set of technical questions that must be addressed at each potential site. To that end, the Nuclear Waste Policy Act of 1982 (NWPA) and NRC regulations require DOE to prepare an SCP for review by NRC and other parties.

The major purposes of the SCP are: (1) to present the issues identified by DOE that must be addressed during the site-characterization and design-development programs and (2) to present DOE's site characterization plans for licensing issues in support of a license application. Because site investigations are exploratory in nature, the NWPA and 10 CFR Part 60 require that DOE provide updates to the SCP every six months during site characterization to report on results and any changes in issues or plans. NRC staff will review each SCP and document the reviews in reports called Site Characterization Analyses (SCA). Staff commentary provided in each SCA and on SCP updates will constitute a major form of guidance to DOE on what information will be needed for licensing.

In addition to guidance contained in the SCAs, there are other forms of guidance (see Figure 1). The staff is preparing technical positions on generic and site specific questions which are important to licensing. As described above, the ISTPs establish a systematic structure for later Site Technical Positions (STPs) which contain specific guidance on what is needed to address one or more licensing issues. Items to be addressed in STPs include specific data/information needed for licensing, methods of data collection and analysis, and treatment of uncertainties. All staff technical positions are made available for public comment. Under an interagency agreement with DOE (48CFR38701), the staff is conducting technical meetings with DOE on an ongoing basis to identify licensing issues at an early time and consult on what information will be used to address them. These interactions are fully documented and placed in public document rooms. As STPs on licensing issues mature through this process, it may be feasible to address some of them in formal rulemaking which would facilitate the licensing review and hearing process. The staff expects to initiate rulemakings on selected licensing issues within the next few years.

Content

The staff has prepared ISTPs for the sites being investigated by DOE's Basalt Waste Isolation Project (BWIP), Nevada Nuclear Waste Storage Investigations Project (NNWSI), and Salt Repository Project (SRP). Each ISTP contains a list of site issues for geology/geophysics, hydrology, geochemistry, geologic repository operations area design/rock mechanics, and waste package. These ISTPs include only those licensing issues needed to determine compliance with 10 CFR Part 60, Subpart E.

This ISTP presents the site issues and rationales for SRP, Gulf Coast Dome Sites. The Technical Position section contains the list of site issues. These site issues are based on the current understanding of the sites, and as additional information becomes available during site characterization, site issues will be added or revised periodically as appropriate.

The Discussion section includes a rationale for the site issues. This rationale explains the significance of the site issue to geologic repository performance. The broadest issues, i.e., those that would appear in the first tier of the hierarchy of issues, are related directly to one or more performance issues (elements of overall system performance listed in the

Development of Issues section). Other issues are related by technical reasoning to the issue(s) directly above in the hierarchy.

Development of Issues

The quantitative performance objectives and the qualitative siting and design criteria of 10 CFR Part 60, Subpart E require assessments of the performance of the overall geologic repository system and its components. The method of issue development is consistent with this approach: a systematic and comprehensive method has been used to identify a heirarchy of questions that are significant to some aspect of performance. This method is illustrated in Figure 3 and is described below.

In developing the issues the following definitions are used:

- Licensing issues are technical questions that the NRC staff will address in order to: 1) complete the licensing assessment of site suitability and/or design suitability in terms of 10 CFR Part 60, Subpart E and 2) adopt the Environmental Impact Statement (EIS) prepared by DOE. Licensing issues include both performance issues and site issues.

- Performance issues are broad questions common to all sites concerning both the operational and long-term performance of the various components of the overall geologic repository system (see Figure 2). These issues are derived directly from the performance objectives of 10 CFR Part 60, Subpart E (see Figure 3).

- Site issues include site specific technical questions about those significant conditions and processes needed to address the performance issues.

In developing licensing issues for these ISTPs, the first step involves breaking down the overall geologic repository system into three time periods addressed by the performance objectives of 10 CFR Part 60: 1) before significant site characterization activities (present), 2) through construction and permanent closure (operational), and 3) after permanent closure (long-term). The next step consists of identifying subsystem elements of the overall geologic repository system consistent with the performance objectives of 10 CFR Part 60 (see Figure 4). From these two breakdowns eleven performance issues are identified which correspond to the individual performance of the various subsystem elements and the three time periods. These performance issues are listed below and their relationships to the performance objectives of 10 CFR Part 60 are shown on Figure 3.

1. How do the design criteria and design address releases of radioactive materials to unrestricted areas within the limits specified in 10 CFR Part 60?

2. How do the design criteria and design accommodate the retrievability option?

3. When and how does water contact the underground facility?

4. When and how does water contact the waste package?

5. When and how does water contact the waste form?

6. When, how, and at what rate are radionuclides released from the waste form?

7. When, how, and at what rate are radionuclides released from the waste package?

8. When, how, and at what rate are radionuclides released from the underground facility?

9. When, how, and at what rate are radionuclides released from the disturbed zone?

10. When, how, and at what rate are radionuclides released from the far field to the accessible environment?

11. What is the pre-waste emplacement groundwater travel time along the fastest path of radionuclide travel from the disturbed zone to the accessible environment?

The next step consists of considering conditions and processes significant to each performance issue based on the current understanding of the relevant physical, chemical, and engineering aspects of the subsystem elements. The significant conditions and processes include those that: (1) exist before geologic repository related disturbance (including before significant site characterization activities), (2) could cause future changes, or (3) result from change. Additionally, the significant conditions and processes fall into the categories of natural (e.g., faulting), repository-induced (e.g., thermally induced stress), and human-induced (e.g., withdrawal of water resources). These significant conditions and processes also include the favorable and potentially adverse siting conditions described in 10CFR60.122; the design criteria of 10CFR60.131-135; and both anticipated and unanticipated processes and events for the time periods during which the NRC performance objectives must be achieved (10CFR60.2).

Many conditions or processes are important to more than one performance issue. For example, questions about faults and fractures combine with various groundwater and geochemistry questions to enable the understanding of the performance issues of water contacting the underground facility, transport within the disturbed zone, far-field transport, and pre-waste-emplacement groundwater travel time. This duplication of significant conditions and processes is minimized by combining those that are similar or repeated into hierarchies of site issues which are then divided into the five technical areas of 1) geology/geophysics, 2) hydrology, 3) geochemistry, 4) geologic operations area design/rock mechanics and 5) waste package. While this grouping is convenient for the staff work, it is important to emphasize that the site issues are derived from an evaluation of information needed to address system performance, which is a multi-disciplinary problem.

The hierarchy of site issues in each technical area is designed to include upper tier issues that are broad and therefore common to all sites. This establishes both a broad technical coverage and an appropriate degree of consistency among issues from one DOE project to another. The various levels of lower tier site issues focus more directly on specific questions about the nature of the individual sites. According to the staff's definition, site issues do not include such questions as methods of data collection and data analysis, performance modeling, performance confirmation testing, and treatment of uncertainties from any source. By staff convention these are questions that cut across all performance issues and site issues and therefore will be addressed in the staff's assessment of each issue and on a selective basis will be developed in the future into detailed STPs. The staff considers these questions to be very important to a licensing assessment and recognizes that they might be subject to contention during the hearing process because they determine the reliability of the information needed to resolve the issues.

Finally, developing the site issues involves judgment as to which conditions and processes are considered to be significant to the performance issues based on the current understanding of the sites. Therefore, every possible condition and process is not listed, rather only those judged by the staff as potentially significant. The staff judgment is based on staff and contractor reviews of site data and documents, site visits, NRC/DOE technical meetings, and research conducted by NRC, DOE, and other organizations. Judgment is also a factor in developing the hierarchy into lower tiers of issues. Different levels of detail reflect the nature of the technical discipline and degree o. knowledge and emphasis on a particular technical area at this stage in site investigations.

Technical Position

Based on current knowledge, this technical position identifies those site issues that the NRC staff considers will be needed at a minimum to determine compliance with 10CFR60 Subpart E. This does not mean that the NRC list of site issues is the only way to express issues. Alternative issue wording or heirarchies of issues could be developed by DOE to address the same technical information.

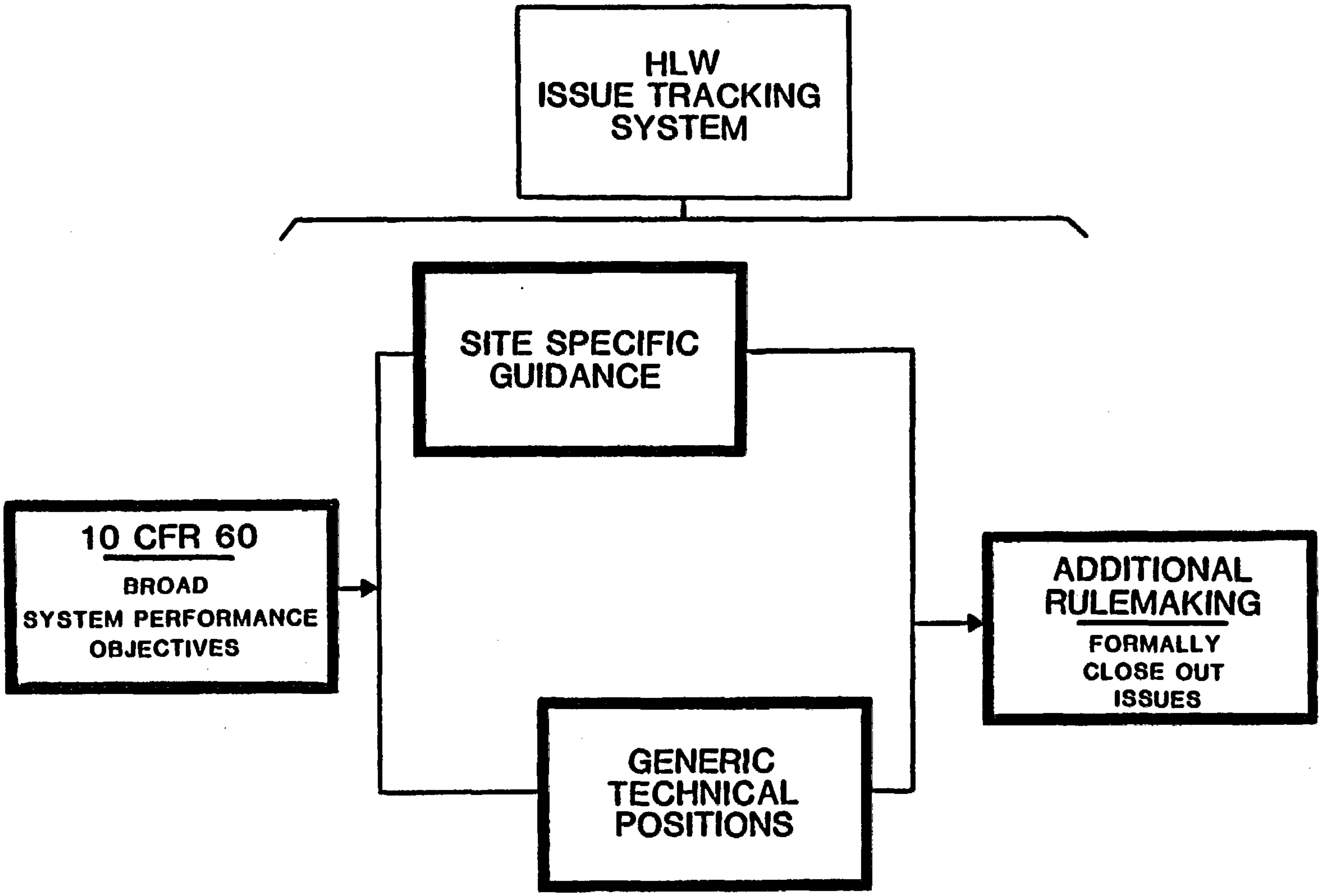
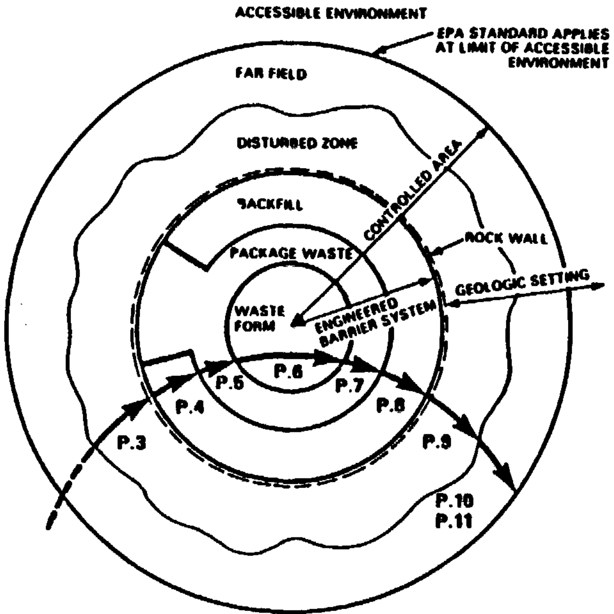
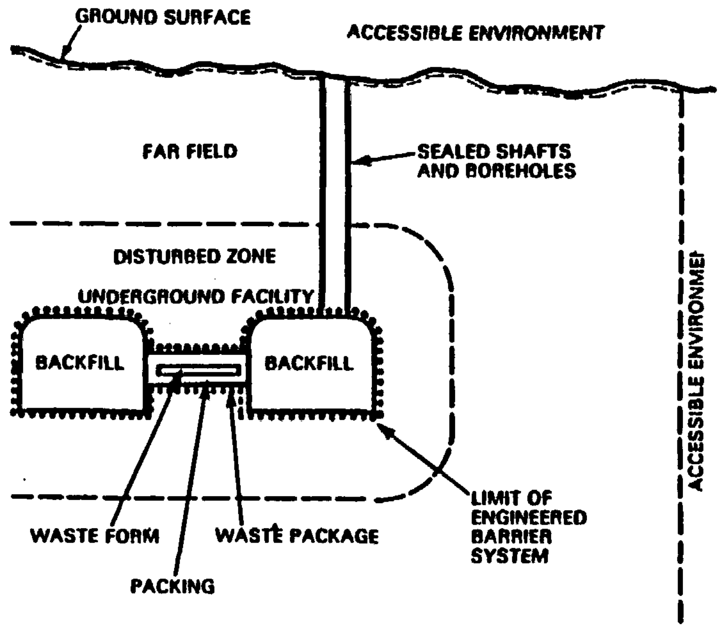



FIGURE 1 NRC HLW LICENSING GUIDANCE PROGRAM

**DIAGRAMMATIC PLAN VIEW (not to scale)**




**DIAGRAMMATIC CROSS SECTION VIEW (not to scale)**




**PERFORMANCE ISSUES**

P.3 When and how does water contact the underground facility?

P.4 When and how does water contact the waste package?

P.5 When and how does water contact the waste form?

P.6 When, how, and at what rate are radionuclides released from the waste form?

P.7 When, how, and at what rate are radionuclides released from the waste package?

P.8 When, how, and at what rate are radionuclides released from the underground facility?

P.9 When, how, and at what rate are radionuclides released from the disturbed zone?

P.10 When, how, and at what rate are radionuclides released from the far field to the accessible environment?

P.11 What is the pre-waste emplacement groundwater travel time along the fastest path of radionuclide travel from the disturbed zone to the accessible environment?

FIGURE 2 REPOSITORY SYSTEM ELEMENTS AND PERFORMANCE ISSUES RELATED TO LONG-TERM PERFORMANCE AFTER PERMANENT CLOSURE

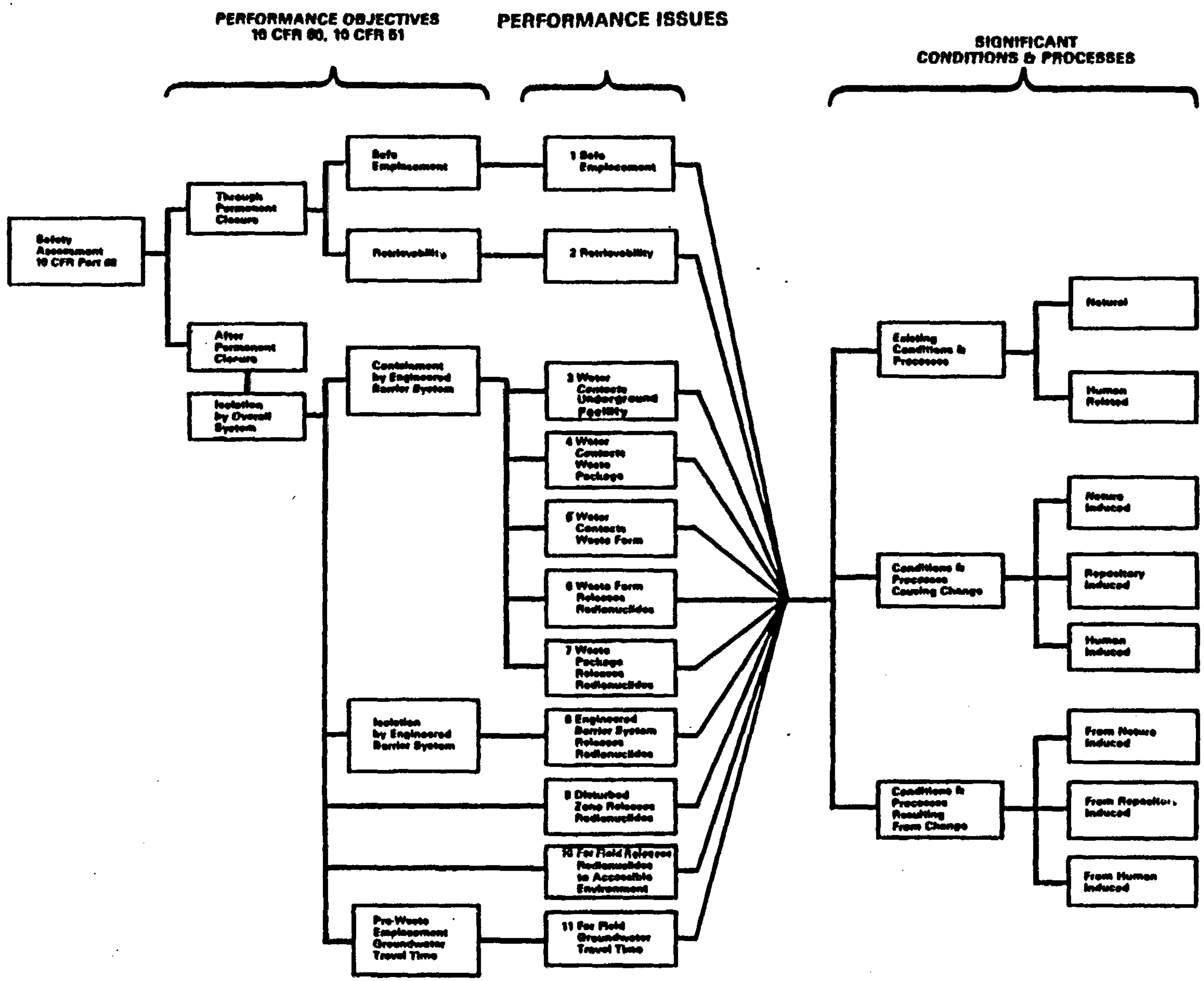



FIGURE 3 LOGIC FOR BREAKDOWN OF NRC ISSUES

# DRAFT SITE ISSUES FOR HYDROLOGY

1.0 Hydrology

1.1 What is the nature of the present groundwater system?

1.1.1 What is the nature of the present groundwater system of the geologic setting?

1.1.1.1 What is (are) the conceptual model(s) of the present groundwater system of the geologic setting?

1.1.1.2 What are the the parameters and conditions, and their areal distributions, that are required to characterize the hydrogeology of the geologic setting and estimate the hydrogeologic conditions surrounding the local system?

1.1.2 What is the nature of the present local groundwater system?

1.1.2.1 What is (are) the conceptual model(s) of the local groundwater system?

1.1.2.2 What are the local flow boundaries, recharge and discharge locations, and mechanisms and amounts of recharge and discharge?

1.1.2.3 How and to what extent is local groundwater flow affected by structural discontinuities?

1.1.2.4 How and to what extent is local groundwater flow affected by stratigraphic and lithologic heterogeneities?

1.1.2.5 What is the hydrochemistry of the local groundwater system?

1.1.2.6 How does the local groundwater system respond to hydraulic stresses?

1.1.2.7 What is the nature of water movement in a salt dome?

1.1.2.8 What is the 3-dimensional distribution of hydrogeologic data at the local scale?

1.1.3 What are the mathematical models that have been and will be used to predict groundwater flow and radionuclide transport, and what are the bases for model selection?

1.2 What is the nature of the present surface water system?

1.2.1 What are the physical characteristics of the surface water system?

1.2.2 What is the potential for flooding within the controlled area?

1.3 What are the types, probabilities and nature of natural changes upon groundwater flow?

1.3.1 What are the types, probabilities, and nature of climatic changes that would affect groundwater flow?

1.4 What are the types, probabilities and nature of human-induced changes (excepting repository-induced changes) that would affect groundwater flow?

1.4.1 How will the relative value of water resources in the area as compared to surrounding areas of similar size affect future water resource development?

1.4.2 What are the types, probabilities and nature of future water resource development and use that would affect groundwater flow?

1.4.3 What are the types and probabilities of exploratory drilling, mine development or other similar human activities that would affect groundwater flow?

1.5 What are the future effects on groundwater flow paths, velocities, fluxes and discharge rates resulting from natural changes?

1.5.1 What are the future effects on groundwater flow paths, velocities, fluxes and discharge rates resulting from climatic changes?

1.5.2 What are the future effects on groundwater flow paths, velocities, fluxes and discharge rates resulting from geologic changes?

1.6 What are the future effects on groundwater flow paths, velocities, fluxes and discharge rates of human-induced changes, excepting repository-induced changes?

1.6.1 What are the future effects on groundwater flow paths, velocities, fluxes and discharge rates resulting from water resource development?

1.6.2 What are the future effects on groundwater flow paths, velocities, fluxes and discharge rates resulting from exploratory drilling, mine development or other similar human activities?

1.7 What are the future effects on groundwater flow paths, velocities, fluxes and discharge rates resulting from underground facility construction, borehole and/or shaft seal failure, and repository-induced changes?

1.7.1 What are the future effects on groundwater flow paths, velocities, fluxes and discharge rates resulting from mechanically-induced changes?

1.7.2 What are the future effects on groundwater flow paths, velocities, fluxes and discharge rates resulting from thermally-induced changes?

Discussion

The rationale for each issue is described in the subsequent discussion. The broadest issues, i.e. those that appear in the first tier of the hierachy of issues and sub-issues are related directly to the performance issues listed in the Background section above. Other issues are related by technical argument to the issue(s) directly above.

1.1 What is the nature of the present groundwater system?

Groundwater is the primary transporting agent for radionuclide migration from a geologic, high-level waste repository. Accordingly, to evaluate completely all performance issues, characterization of the groundwater system is necessary. For example, the potential for inflow of groundwater into the underground facility during the operational phase is a consideration in evaluating performance issues 3 through 5 relate directly in flow of groundwater into the underground facility while performance issues 6 through 10 relate directly to release of radionuclides from the underground facility via the groundwater pathway (this does not assume groundwater is the only release pathway). Performance issue 11 is based on a requirement for site suitability which is that the pre-waste emplacement groundwater travel time along the fastest path of radionuclide travel to the accessible environment be greater than 1,000 years. Finally, potential impacts of the repository on the present groundwater system is a likely consideration in evaluating performance issue 12. Evaluation of these performance issues depends upon an understanding of components of the groundwater system that are identified, relative to varying levels of scale and detail, in the following issues.

1.1.1 What is the nature of the present groundwater system of the geologic setting?

"Geologic setting", as defined in 10 CFR Part 60, means the geologic, hydrologic and geochemical systems of the region in which a geologic repository operatoins area is or may be located. The groundwater system of the geologic setting should be characterized to provide general understanding of groundwater flow into and out of the local groundwater system (see site issue 1.1.2), although performance issues 3 through 11 are more directly addressed by local groundwater characterization.

An understanding of the groundwater system of the geologic setting is also necessary to assess the impacts of natural, human-induced, and repository-induced changes upon regional groundwater flow patterns (see site issues 1.5, 1.6, and 1.7 below).

1.1.1.1 What is (are) the conceptual model(s) of the present groundwater system of the geologic setting?

To evaluate the nature and significance of hydrogeologic processes, it is necessary to consider them in a defined hydrogeologic setting or conceptual model. A conceptual model consists of the minimum features of the real system needed to define qualitatively the relevant behavior of the system. The conceptual model of the groundwater system of the geologic setting includes such components as the salt dome, hydrostratigraphic units, recharge and discharge areas, general flow patterns, locations of hydrologic stresses, and degree of transience. The regional conceptual model provides a basis for quantitative models. A range of defensible conceptual models of the regional groundwater flow system should be developed that brackets all reasonable interpretations of data. Subsequent investigations will then be used to rank conceptual models on the basis of relative likelihoods.

1.1.1.2 What are the parameters and conditions, and their areal distributions, that are required to characterize the hydrogeology of the geologic setting and estimate the hydrogeologic conditions surrounding the local system?

Knowledge of the parameters, conditions and associated uncertainties is required for hydrogeologic characterization of the geologic setting. Measured parameter values are generally more reliable than values obtained indirectly, but it is impossible to measure hydrogeologic parameters everywhere. Therefore, extrapolated and interpolated values and values obtained from models are often used to provide additional parameter values to reflect sufficiently the heterogeneities within system components of the geologic setting. Such parameters include vertical and horizontal hydraulic conductivities, storativities, hydraulic heads, and total porosities. Hydrochemical data will aid in developing conceptual groundwater flow models of the geologic setting such as by providing verification of hydrostratigraphic units. Estimates of the mass balance of the groundwater system of the geologic setting and establishment of the general characteristics of groundwater flow into and out of the local system will depend upon defining boundaries of the groundwater system of the geologic setting, and determining recharge and discharge locations, mechanisms, and amounts.

1.1.2 What is the nature of the present local groundwater system?

The local groundwater system is the controlled area, and any portion of the accessible environment which may need to be included in the detailed characterization necessary to make qualitative calculations of groundwater travel times from the disturbed zone to the accessible environment referred to in performance issue 11.

An understanding of the local groundwater system is also necessary to assess the impacts of natural, human-induced, and repository-induced changes upon groundwater travel times and radionuclide release rates to the accessible environment (see site issues 1.5, 1.6, and 1.7).

1.1.2.1 What is (are) the conceptual model(s) of the local groundwater system?

Conceptual models of the local groundwater system should be based on sufficient hydrogeologic data derived from characterizing all aspects of the flow system which significantly influence pre-emplacement groundwater travel times and post-emplacement radionuclide transport from the repository to the accessible environment (see site issues 1.1.2.2 through 1.1.2.8).

A range of defensible conceptual models of the local flow system should be developed that brackets all reasonable interpretations of data. They will be the basis for formulating mathematical models to compute travel times and radionuclide release rates. Data from subsequent field investigations will be used to rank alternative conceptual models on the basis of relative likelihood.

1.1.2.2 What are the local flow boundaries, recharge and discharge locations, and mechanisms and amounts of recharge and discharge?

The areal and vertical extent of the local groundwater flow system as it relates to potential flow paths and repository performance issues 3 through 11 should be defined. The temporal and spatial distribution of boundaries and recharge and discharge rates within the local flow system will significantly affect flow paths and may therefore affect travel times to the accessible environment.

1.1.2.3 How and to what extent is local groundwater flow affected by structural discontinuities?

Structural discontinuities, including rim synclines, karst features, salt interfaces with caprock and sheath, features realted to dissolution of salt and caprock, and faults associated with salt dome growth, are potentially the most important factors governing groundwater flow rates and directions in the area immediately surrounding the salt dome. They may constitute direct avenues for contaminant movement to the accessible environment or provide a flow path for salt dissolution; conversely, they may be a barrier to flow.

Anomalous zones within the salt dome interior may affect local and repository-scale water movement. Gulf Coast Interior Region salt domes typically are composed of salt spines surrounded by inclusion-bearing anomalous salt. Inclusions are brines, petroleum products, pressurized gases, and clastic non-salt materials such as sand, clay, and carbonates. These anomalies may provide direct avenues for contaminant movement to the accessible environment or provide a flow path permitting salt dissolution.

1.1.2.4 How and to what extent is local groundwater flow affected by stratigraphic and lithologic heterogeneities?

Stratigraphic and lithologic heterogeneities including such examples as facies changes resulting from dome growth exert primary control on hydrogeologic properties and the movement of groundwater within the flow system. Discontinuities may act as preferential flow paths due to the presence of high hydraulic conductivity material or as barriers to groundwater flow if low hydraulic conductivity materials are present.

1.1.2.5 What is the hydrochemistry of the local groundwater system?

In the complex hydrogeologic system associated with a salt dome, identification of flow paths and verification of salt dissolution may be facilitated or supported by the hydrochemistry of the flow systems within and surrounding the salt dome. The accuracy of conceptual models including verification of hydrostratigraphic units should depend on the interpretation of both hydrochemistry and hydrogeology. Hydrochemical data are required to determine the potential for density-driven flow caused by differences in brine concentrations.

1.1.2.6 How does the local groundwater system respond to hydraulic stresses?

Pumping, fluid injection, exploitation of mineral resources, collapse of dissolution features and repressurization of the host rock are among the changes that may stress the hydrogeologic system. Therefore, to assess the impacts of ongoing stresses on groundwater flow paths, velocities, fluxes and discharge rates, as well as the future effects of natural, human-induced and repository-induced changes (see site issues 1.5, 1.6, and 1.7), characterization of the groundwater system should include, through field testing to the extent possible, system responses to an induced stress.

1.1.2.7 What is the nature of water movement in a salt dome?

The characterization of salt requires separate evaluation with emphasis placed on characterizing those hydrogeologic and general physical properties and processes most important to repository performance. Because groundwater flow travel times and radionuclide transport may be affected by hydrogeologic properties of domal salt, those parameters needed to characterize water movement in salt should be identified.

Relevant hydrogeologic processes in salt may include hydraulically-, chemically-, thermally- or density-induced flow, fracture flow, or flow related to brine migration.

1.1.2.8 What is the 3-dimensional distribution of hydrogeologic data at the local scale?

The distribution of measured and interpolated hydrogeologic parameters for aquifers and aquitards surrounding the salt dome at the local scale will play an important role in determining groundwater flow paths and travel times and associated uncertainties. Such data include vertical and horizontal conductivities, storativities, hydraulic heads, and total porosities throughout each hydrostratigraphic unit. These data will also verify the identification of hydrostratigraphic units.

1.1.3 What are the mathematical models that have been and will be used to predict groundwater flow and radionuclide transport,and what are the bases for model selection?

A mathematical model is the translation of the conceptual understanding of the groundwater flow system into mathematical expressions describing the physical processes. In general, mathematical models may be simplified and solved analytically or converted to a system of algebraic equations that are solved numerically. Mathematical models quantify conceptual models to verify the compatibility of conceptual models with field measurements, and they can be used to predict future flow rates and migration rates of radionuclides. It is necessary to show that the mathematical models used are representative of the physics of the hydrogeological processes being described. Mathematical models should also verify system response to hydraulic stresses and vice versa.

1.2 What is the nature of the present surface water system?

Performance Issues 1 and 2 relate design criteria and conceptual design of the geologic repository to: (A) releases of radioactive materials to unrestricted areas (within limits specified in 10 CFR Part 20); and (B) the retrievability option. These primarily are operational considerations. An understanding of the nature of the present surface water system is essential to determine the potential for flooding of surface and underground facilities. Determination of the potential flooding will be an important consideration in evaluating performance issues 1 and 2.

1.2.1 What are the physical characteristics of the surface water system?

The potential for flooding within a controlled area in the Gulf Coast Interior salt domes is in part a function of the physical characteristics of the surface water system. For example, specific data on drainage areas, and flow patterns for various channels, channel cross-sections and stage-discharge relationships of the appropriate drainage basins of the Gulf Coast Interior region are the types of information necessary to define the physical characteristics of the surface water drainage system. In addition, either occupancy within or modification of flood plains are considered relevant physical characteristics of the surface water drainage system.

1.2.2. What is the potential for flooding within the controlled area?

Flooding within the controlled area (including surface and underground facilities) could affect isolation of the waste and will be a consideration in the evaluation of repository performance as discussed in site issue 1.2. Typically, evaluation of potential flooding includes identification of historical flood events and calculation of peak flows (including peak velocities and flood stages for flood events ranging in magnitude from a 100-year flood to a probable maximum flood). In addition, evaluation of failure of existing or planned man-made surface water impoundments needs to be included in the analysis of flooding potential.

1.3 What are they types, probabilities and nature of natural changes upon groundwater flow?

Natural processes which may change site conditions and the existing groundwater system need to be considered in determining whether long-term performance of the repository will comply with radionuclide release standards. Specifically, future effects of such natural processes on groundwater flow need to be considered in evaluating performance issues 3 through 10 (see site issue 1.5). Identifying expected and unexpected processes followed by determining probabilities of occurrence of the various types of processes identified are steps taken to facilitate the elimination of some processes from further considerations and provides a basis for determining necessary consequence assessments.

Identified below is one particular natural process which is subject to change and is applicable to Gulf Coast Interior Salt Domes (site issue 1.3.1; Climate). Other natural processes which could change are included in the general category of geologic processes. Issues related to the types, probabilities, and nature of geologic changes are outside the scope of this Site Technical Position and are included in Gulf Coast Interior Salt Domes Site Technical Position 5.0, "Geology Issues for the Gulf Coast Interior Salt Domes". However, effects on the groundwater system of plausible future geologic changes will be a consideration under site issue 1.5.2 of this Site Technical Position.

1.3.1 What are the types, probabilities, and nature of climatic changes that would affect groundwater flow?

Climatic variations are natural changes known to have occurred in the past over the same lengths of time in which repository performance will be assessed. Climatic processes that may change site conditions and the existing groundwater system need to be considered in addressing the concerns about the long-term repository performance reflected in performance issues 3 through 10.

1.4 What are the types, probabilities and nature of human-induced changes (excepting repository-induced changes) that would affect groundwater flow?

Human-induced changes to site conditions and the existing groundwater system need to be considered in addressing the concerns about long-term repository performance reflected in performance issues 3 through 10.

1.4.1 How does the relative value of water resources in the area as compared to surrounding areas of similar size, affect future water resource development?

Groundwater and surface water exploitation or manipulation could affect groundwater flow rates and paths. Assessment of the value of water resources surrounding the salt dome coupled with the historical development of water demand will provide a basis for establishing the potential magnitude of future water resource development which could impact repository performance.

1.4.2 What are the types, probabilities and nature of future water resource development and use that would affect groundwater flow?

Resource development of surface water and groundwater as well as drilling of injection wells are examples of future uses that could affect groundwater flow. Identification of the types of water use activities that might occur as well as determination of the probabilities and nature of those water use activities provides a basis for determining necessary consequence assessments.

1.4.3 What are the types and probabilities of exploratory drilling, mine development or other similar human activities that would affect groundwater flow?

Exploratory drilling and mining activities are recognized modes of human-induced change that could impact repository performance. Identification of the types as well as determination of the probabilities of such human activities provides a basis for determining necessary consequence assessments.

1.5 What are the future effects on groundwater flow paths, velocities, fluxes and discharge rates resulting from natural changes?

The future effects of plausible natural changes on groundwater flow paths, velocities, fluxes and discharge rates relate directly to the assessment of repository performance as reflected in performance issues 3 through 10.

1.5.1 What are the future effects on groundwater flow paths, velocities, fluxes and discharge rates resulting from climatic changes?

The future effects of climatic changes on groundwater flow paths, velocities, fluxes and discharge rates relate directly to the assessment of repository performance as reflected in performance issues 3 through 10.

1.5.2 What are the future effects on groundwater flow paths, velocities, fluxes and discharge rates resulting from geologic changes?

Geologic changes that could effect groundwater flow include such examples as regional tectonic movements and associated local faults, folds and fractures, and changes due to salt dissolution and flowage. Geological issues are identified in Gulf Coast Interior Salt Domes STP 5.0, "Geology Issues for the

Gulf Coast Interior Salt Domes." The future effects of such geologic changes on groundwater flow paths, velocities, fluxes and discharge rates relate directly to the assessment of repository performance as reflected in performance issues 3 thorough 10.

1.6 What are the future effects on groundwater flow paths, velocities, fluxes and discharge rates of human-induced charges, excepting repository induced changes?

The expected effects of plausible human-induced changes over time on groundwater flow paths, velocities, fluxes and discharge rates relate directly to the assessment of repository performance as reflected in performance issues 3 through 10.

1.6.1 What are the future effects on groundwater flow paths, velocities, fluxes and discharge rates resulting from water resource development?

Altering of hydraulic gradients, and providing interaquifer connection are examples of expected effects over time on groundwater flow resulting from such activities as water resource development and drilling of injection wells.

1.6.2 What are the future effects on groundwater flow paths, velocities, fluxes and discharge rates resulting from exploratory drilling, mine development or other similar human activities?

Altering of hydraulic gradients, and providing interaquifer connection are examples of expected effects over time on groundwater flow resulting from mineral resource development.

1.7 What are the future effects on groundwater flow paths, velocities, fluxes and discharge rates resulting from underground facility construction, borehole and/or shaft seal failure, and repository-induced changes?

The future effects upon groundwater flow into and out of the repository due to plausible changes resulting from underground facility construction, borehole and/or shaft seal failure, and the presence of the repository need to be considered in evaluating both operational (performance issues 1 and 2) and long-term performance (performance issues 3 through 10).

1.7.1 What are the future effects on groundwater flow paths, velocities, fluxes and discharge rates resulting from mechanically-induced changes?

Mechanically-induced changes may result from construction of shafts and the underground facility. For example, during repository construction, physical changes such as fracturing will occur in the host rock. During and after waste emplacement, shaft seal failure or dissolution along the exterior of mine shafts or boreholes could provide a means to saturate the repository and/or provide a pathway for radionuclide transport. Additional changes during and after waste emplacement will include repressurization of the host rock and surrounding geologic units.

1.7.2 What are the future effects on groundwater flow paths, velocities, fluxes and discharge rates resulting from thermally-induced changes?

Thermally-induced changes will occur to the groundwater system from the thermal load generated by the high-level wastes. Flow paths, velocities, fluxes and discharge rates will be influenced by bouyancy and convection of heated groundwater after waste emplacement. Thermal effects may also create environments in which some minerals become unstable, thereby altering material properties affecting hydrogeologic parameters.

# DRAFT SITE ISSUES FOR WASTE PACKAGE

## 2.0 WASTE PACKAGE

The waste package specific issues presented below are intended to elicit information concerning waste package design and performance prediction that will enable an assessment to be made of the ability of each waste package component to meet its functional requirements.

2.1
When, how, and at what rate will brine penetrate the packing around the waste package and contact the container?

2.1.1
What are the possible mechanisms and associated flow rates by which brine will penetrate the packing materials around waste package containers?

2.1.2
What will be the physical characteristics (e. g., temperature, pressure, and flow rates) of the brine reaching the waste package container as a function of time?

2.1.3
What will be the chemical characteristics (e. g., Eh, pH, and chemical composition) of the brine reaching the waste package container as a function of time?

2.1.3.1
How will the chemical characteristics of the brine reaching the waste package container be affected by radiolysis?

2.1.3.2
How will the chemical characteristics of the brine contacting the waste package container be affected by chemical reaction with the packing and container materials?

2.1.4
To what extent, as a function of time, will brine migration, temperature, radiation, or other effects change the ability of waste package packing materials to control the flow and chemical composition of brine passing through those materials?

2.1.5
How will the partial pressure of oxygen vary with time in the vicinity of the waste package packing and container?

2.1.5.1
How will the time dependence of oxygen removal from the waste package packing materials vary as a function of brine migration and composition, temperature, pressure, radiolysis and other parameters?

2.1.5.2
How will the time dependence of oxygen removal from the waste package packing materials vary as a function of the composition and physical structure (e.g., density, cracks and pore distribution) of the packing?

2.1.6
How will the design features of the packing accomodate all potential natural and waste package - induced conditions?

2.2
When, how, and at what rate will brine penetrate the waste package container?

2.2.1
What will the physical properties of the waste package container materials be as affected by temperature, radiation, interaction with the packing materials, brine migration, and other effects?

2.2.2
What will the chemical properties of the waste package container materials be as affected by temperature, radiation, interaction with the packing materials, brine migration, and other effects?

2.2.3
What are the possible mechanical failure modes for the waste package container?

2.2.3.1
What will be the mechanical loads on the waste package container as a function of time?

2.2.3.1.1
What will be the magnitude of the lithostatic/hydrostatic loads on the waste package container and the resultant stress developed within the container as a function of time?

2.2.3.1.2
What will be the magnitude of the thermal stresses developed within the waste package container as a function of time?

2.2.3.2
How will the packing materials around the waste package container affect the loading?

2.2.4
What are the potential corrosion failure modes for the waste package container?

2.2.4.1
What are the rates of corrosion as a function of time for the various corrosion modes of the waste package container?

2.2.4.2
What are the effects of radiation on the corrosion failure modes and associated corrosion rates for the waste package container?

2.2.4.2.1
What is the predicted rate of radiolytic generation of hydrogen, oxygen, and other species due to gamma radiation in the vicinity of the waste package container?

2.2.4.2.2
How will the generation of hydrogen, oxygen, and other species affect the corrosion modes and rates of the waste package container?

2.2.4.3
What effects will the packing materials around the waste package container have on the corrosion mechanisms and rates for the container?

2.2.4.4
Will microbes affect corrosion of the waste package container, and if so, how?

2.2.5
What are the anticipated physical dimensions of waste package container breach as a function of time?

2.2.6
What will be the physical characteristics (e.g., temperature, pressure, and flow rate) of the brine penetrating the waste package container and reaching the waste form as a function of time?

2.2.7
What will be the chemical characteristics (e.g., Eh, pH, and chemical constituents of the brine penetrating the waste package container and reaching the waste form as a function of time?

2.2.8
How will the design of the waste package container accomodate all potential natural and waste package-induced conditions?

2.3
When, how, and at what rate will radionuclides be released from the waste form?

2.3.1
What are the physical, chemical, and mechanical properties of the waste form, how do those properties of the waste form change with time, and how will such changes alter the ability of the waste form to contribute to the overall performance of the repository system or impact the performance of other barrier materials and properties of the site?

2.3.2
What is the solubility of the waste form under the range of potential repository conditions?

2.3.2.1
What are the possible dissolution mechanisms of the waste form under the range of potential repository conditions?

2.3.2.1.1
Which waste form dissolution mechanism or mechanisms are most likely?

2.3.2.1.2
What are the rates of dissolution associated with the potential waste form dissolution mechanisms?

2.3.2.2
What non-radioactive dissolution products are likely to be produced from the waste form?

2.3.2.3
What are the solubilities of the radionuclides released from the waste form?

2.3.2.4
What will be the chemical species of the radionuclides released from the waste form?

2.3.3
What colloids or other suspended particles will be produced from the waste form?

2.3.3.1
How may the formation of colloidal particles affect waste form degradation?

2.3.3.2
How may radionuclides that are released from the waste form be transported in colloids or other suspended particle form?

2.3.4
What are the predicted ranges of residence times of a unit volume of brine in contact with a unit area of waste form as a function of time?

2.3.4.1
For spent fuel, how does the fuel rod cladding change the predicted effective residence time of a unit volume of brine in contact with a unit area of waste form?

2.3.4.2
For reprocessed fuel, how may alterations in physical form (e.g., cracking) alter the predicted effective residence time of a unit volume of brine in contact with a unit area of waste form?

2.3.5
How will packing, container materials (including overpacks, canisters, and any special corrosion-resistent alloys or spent fuel rod cladding, if applicable) and/or their alteration products interact with the waste form to cause its alteration and/or effect release of radionuclides?

2.3.6
For spent fuel, what are the potential damage and failure mechanisms for the fuel rod cladding?

2.3.6.1
What is the predicted rate of failure for each of the potential failure mechanisms for spent fuel?

2.3.6.2
What is the predicted size of cladding breach associated with each of the potential spent fuel cladding failure mechanisms?

2.3.6.3
For fuel rods with defected cladding, how will the presence of defects alter the radionuclide retention capability of the spent fuel waste form?

2.3.7
How will the design of the waste form accomodate all potential natural and waste package induced conditions?

2.4
How and at what rates will radionuclides migrate through failed waste packages?

2.4.1
What will be the convective flows in the waste package as a function of time?

2.4.2
What are the transport and retardation processes important to the flux of radionuclides with time in waste package packing materials?

2.4.3
How will the radionuclide species (i.e., particles, colloids, and solubles) change with time in the waste package?

2.4.4
What will be the solubility as a function of time of species incorporating radionuclides in the vicinity of the waste package packing materials?

2.4.5
Will alpha radiation in the waste package packing materials affect chemistry and hence transport and radionuclide species identification?

2.4.6
Will microbes affect transport in waste package packing materials? If so, how?

2.5
How does the waste package design address releases of radioactive materials to unrestricted areas within the limits specified in 10 CFR 20?

2.5.1
How will the waste package shielding contribute to the maintenance of radiation doses, levels, and concentrations within the limits of 10 CFR 20?

2.5.2
How will the waste package design provide assurance that necessary safety functions will be carried out in the geologic repository area?

2.5.2.1
How will the waste package design protect against natural phenomena and environmental conditions anticipated at the geologic repository area?

2.5.2.2
How will the waste package design protect against the dynamic effects of equipment failure and similar events?

2.5.2.3
How will the waste package be designed to perform its safety functions during and after credible fires or explosions in the geologic repository area?

2.5.3
How will the waste package design provide protection against radiation exposures and offsite releases prior to permanent closure?

2.6
How does the design of the waste package accomodate the requirement that the waste should be retrievable at any time up to 50 years after emplacement?

2.6.1
What features of the waste package container will be provided to facilitate transportation and retrievability before emplacement or retrievability from the underground facility after emplacement?

2.6.2
What features of the waste package packing will facilitate retrievability of the waste package after emplacement?

2.6.3
What labels or other means of identification will be provided for the waste package to facilitate retrievability?

2.6.3.1
How will the waste package design provide that the identification on the waste package will not impair the integrity of the waste package?

2.6.3.2
How will the waste package design provide that the identification information on the waste package will be legible at least to the end of the period of retrievability?

2.6.3.3
How will the waste package design provide that each waste package identification will be consistent with the waste package's permanent written record?

2.7

How will the waste package design preclude explosive, pyrophoric, and chemically reactive materials?

2.7.1

How will the waste package design preclude free liquids in an amount that could compromise the ability of the waste package to achieve the performance objectives related to containment of HLW (because of chemical interaction or formation of pressurized vapor) or the prevention of spillage and spread of contamination in the event of waste package perforation during the period through permanent closure?

2.7.2

How will the waste package design ensure that the radioactive wastes will be in solid form in a sealed container?

2.7.3

How will the waste package design ensure that particulate waste forms will be consolidated (for example, by incorporation into an encapsulating matrix) to limit the availability and generation of particulates?

2.7.4

How will the waste package design ensure that either (a) all combustible radioactive wastes have been reduced to a non-combustible form or (b) a fire involving the waste packages containing combustibles will not (1) compromise the integrity of other waste packages, (2) adversely affect any structures, systems or components important to safety, or (3) compromise the ability of the underground facility to contribute to waste isolation?

2.8

What are the conditions that might affect criticality in the vicinity of the waste package?

2.8.1

How will the waste form radionuclide inventory and the overall design (including shielding) of the waste package be controlled to ensure that criticality will not be reached during the handling and storage of waste packages during the operational phase of the repository?

2.8.2

By what means could actinides be concentrated in the packing materials to create a potential for criticality after emplacement of the waste packages?

2.9 How will the design of the waste package accomodate the monitoring of the package without adversely affecting waste package integrity?

DISCUSSION

The rationale for each specific issue is contained in the following discussion. The issues are intended to provide guidance to DOE with respect to what the NRC staff considers important in determining compliance with the provisions of (a) 10 CFR 60.113, "Performance of the geologic repository operations area through permanent closure" that address waste package performance, (b) those portions of 10 CFR 60.135, "Criteria for the waste package and its components" which merit further elaboration, and (c) 20 CFR 60.143, "Monitoring and testing waste packages."

2.0 WASTE PACKAGE

The performance objective of 10 CFR Part 60 addressing containment (60.113(a)(1)(ii)(A)) requires that containment of HLW within the waste packages be substantially complete for a period of not less than 300 to 1,000 years (period to be determined by the Commission) after permanent closure of the repository. Under reasonably foreseeable conditions, release of HLW will be through dissolution of, or leaching from, the waste form by brine after the brine has migrated up the thermal gradient through the packing material and has corroded the container to the degree that it fails. Therefore, an understanding of (1) the time, rate, and nature of the brine contacting and affecting the components of the waste package and (2) the time, rate, and nature of the release and migration of radionuclides from the waste form out through the layered components of the waste package is essential to being able to demonstrate compliance with this performance objective. Waste package specific issues 2.1 through 2.4 and associated sub-issues address such flow-in, flow-out phenomena as they affect waste package design and post-emplacement performance prediction, while issues 2.5 through 2.9 address other pre- and post-emplacement concerns.

2.1

When, how, and at what rate will brine penetrate the packing around the waste package and contact the container.

Before brine contacts the waste it must penetrate the packing and then any containers separating the packing from the waste form. Depending on the type of materials used, the packing may significantly affect the time and rate at which brine reaches the container, and may be designed to delay or reduce such contact. Further, for packing materials other than crushed salt of the same composition as the repository site the packing is likely to alter the brine's chemical composition and thereby affect the processes by which brine will degrade the container. Regardless of whether DOE wishes to take advantage of these processes to enhance waste package performance, it will be necessary for the NRC to determine whether they have any adverse effects on its performance.

2.1.1
What are the possible mechanisms and associated flow rates by which brine will penetrate packing materials around waste package containers?

In order to assess the effects of packing on the rate and chemical composition of brine reaching the containers, it will be necessary to determine how the brine penetrates the packing. Possible mechanisms might include porous flow through a packing unchanged by time, very slow flow inhibited by swelling of the packing due to saturation, or flow through cracks in the packing resulting from thermal degradation of the packing materials.

2.1.2
What will be the physical characteristics (e.g., temperature, pressure, and flow rates) of the brine reaching the waste package container as a function of time?

This information is necessary to define the time-dependent physical environment of the containers to be able to model the physical, and part of the chemical, processes involved in container degradation.

2.1.3
What will be the chemical characteristics (e.g., Eh, pH, and chemical composition) of the brine reaching the waste package container as a function of time?

This information is necessary to define the time-dependent chemical environment of the containers to be able to model the chemical, and part of the physical, processes involved in container degradation.

2.1.3.1
How will the chemical characteristics of the brine reaching the waste package container be affected by radiolysis?

Brine migrating through the packing toward the waste package container will be exposed to gamma irradiation (alpha irradiation as well if the container has been breached). This can result in a variety of effects involving hydrolysis of the water and formation of colloidal sodium and chlorine. Because this can have a marked effect on the environment and performance of the containers, it must be taken into account in waste package design and performance prediction.

2.1.3.2

How will the chemical characteristics of the brine contacting the waste package container be affected by chemical reaction with the packing and container materials?

The chemical composition, Eh, and pH of the brine can be affected by reaction with the packing and container materials with the result that the rate of penetration of the container and reaction with the waste form can be enhanced or retarded. Such changes should be taken into account in the waste package design and performance prediction.

2.1.4

To what extent, as a function of time, will brine migration, temperature, radiation or other effects change the ability of waste package packing materials to control the flow and chemical composition of brine passing through those materials?

This issue recognizes that the packing materials may not a priori be presumed to be stable in the environment which they will be placed over the interval of interest for assessing repository performance. Some demonstration, perhaps through the use of bounding analyses based on test data, will be needed to demonstrate that the performance of the package does not change in ways that unacceptably degrade the performance of the waste package as a whole.

2.1.5

How will the partial pressure of oxygen vary with time in the vicinity of the waste package packing and container?

This question is covered in a general sense in item 2.1.3 above. It is highlighted here to emphasize the NRC staff's concern that the rate, speciation, and behavior of the HLW radionuclides released from the waste form are expected to be strongly dependent on the oxygen activity present. The staff further considers that assessment of oxygen activity and the reliability of that assessment are major technical questions which must be addressed early.

2.1.5.1

How will the time dependence of oxygen removal from the waste package packing materials vary as a function of brine migration and composition, temperature, pressure, radiolysis and other parameters?

This issue is intended to address the changes in chemical characteristics within the packing which may influence the quantity of oxygen available at the container surface as a function of time. Such changes may result from processes such as corrosion (oxygen depletion) and diffusion and radiolysis (oxygen replenishment).

2.1.5.2

How will the time dependence of oxygen removal from the waste package packing materials vary as a function of the composition and physical structure (e.g., density, cracks and pore distribution) of the packing?

This issue is intended to address the changes in physical characteristics within the packing which may influence the quantity of oxygen available at the container surface as a function of time. Such changes may result from densification of the packing as a result of lithostatic/hydrostatic pressure or porosity and crack formation from steam generation or wet/dry cycling.

2.1.6

How will the design features of the packing accomodate all potential natural and waste package-induced conditions?

This issue is intended to draw upon the analyses developed for the preceding issues to assess the predicted performance of a specific packing material as affected by method of emplacement, configuration, waste package components, or natural components of the repository. Factors that should be accounted for include, but are not restricted to, the packing material porosity, aggregate size and size distribution, the method of emplacement of the packing, and the emplacement configuration.

Waste package issue 2.2 and associated sub-issues are derived from performance issue number 5; when, how, and at what rate will brine contact the waste form?

2.2

When, how, and at what rate will brine penetrate the waste package container?

One of the performance objectives in 10 CFR 60 addresses the interval during which the containment of HLW is substantially complete (10 CFR 60(a)(1)(ii)(A)). Therefore, this issue addresses the fact that the interval during which the container remains intact will be of major significance in assessing the interval over which containment of HLW will be substantially complete. To assess the period of time during which the container will remain intact, mechanical and chemical failure modes must be considered both individually as well as synergistically.

2.2.1
What will the physical properties of the waste package container materials be as affected by temperature, radiation, interaction with the packing materials, brine migration, and other effects?

This issue recognizes that container properties may not a priori be presumed to be constant in the environment in which it will be placed over the interval of interest for assessing repository performance. Some demonstration, perhaps through the use of bounding analyses, will be needed to demonstrate that the container does not change in ways that unacceptably degrade the performance of the waste package as a whole. For example, the effect of radiation on the yield strength of the container material will be subject to scrutiny.

2.2.2
What will the chemical properties of the waste package container materials be as affected by temperature, radiation, interaction with the packing materials, brine migration, and other effects?

The rationale for needing this information is comparable to the discussion in 2.2.1 above.

2.2.3
What are the possible mechanical failure modes for the waste package container?

Container breach may occur through a variety of mechanisms, including crushing due to lithostatic stresses, perhaps altered by hydrostatic effects or by corrosion processes. The following sub-issues have been developed to assess the importance of potential failure modes.

2.2.3.1
What will be the mechanical loads on the waste package container as a function of time?

The containers may be subjected to mechanical loads and stresses from the geologic environment, the waste package induced environment or from container fabrication. Examples of such stresses could be lithostatic loads, thermal stresses and residual stresses, respectively. To assess the importance of the potential mechanical failure modes, an understanding of the mechanical loads on and resulting stresses in the container will be necessary.

2.2.3.1.1

What will be the magnitude of the lithostatic/hydrostatic loads on the waste package container and the resultant stress developed within the container as a function of time?

The major contribution of stress on the container will probably result from the surrounding rock (lithostatic/hydrostatic loads). These loads may also vary with time. Therefore, to determine their effect on the mechanical failure modes, an evaluation of the resulting stresses in the container will be necessary.

2.2.3.1.2

What will be the magnitude of the thermal stresses developed within the waste package container as a function of time?

All waste containers will be exposed to elevated temperatures from the heat produced as a result of radioactive decay. The period of duration of this condition and the magnitude of the temperature attained will vary depending on the waste form and the radionuclides inventory. To assess the effect of temperature on the mechanical failure modes, an understanding of the thermal stresses developed in the container will be necessary.

2.2.3.2

How will the packing materials around the waste package container affect the loading?

Packing material placed around the container may minimize the mechanical loads permanently or temporarily or may transmit or even intensify (by swelling) the loads on the container. Therefore, the effects of packing (if utilized) must be evaluated.

2.2.4

What are the potential corrosion failure modes for the waste package container?

To determine the time and nature of likely container breach, it will be necessary to demonstrate that the failure mode or combination of failure modes associated with that breach will be the most rapid of those failure modes which may be postulated to occur. It is, therefore, necessary to identify the full set of failure modes, including corrosion failure modes, and to determine which are the most significant.

2.2.4.1
What are the rates of corrosion as a function of time for the various corrosion modes of the waste package container?

This issue is intended to help develop the overall corrosion rate in order to determine the time until waste package failure.

2.2.4.2
What are the effects of radiation on the corrosion failure modes and associated corrosion rates for the waste package container?

This issue is intended to address the possibility that the presence of radiation may enhance the container corrosion rate and produce failure sooner than expected in the absence of a radiation environment.

2.2.4.2.1
What is the predicted rate of radiolytic generation of hydrogen, oxygen and other species due to gamma radiation in the vicinity of the waste package container?

It is necessary to identify the type and amount of species likely to be produced by radiolysis in order to characterize the effect of the radiation environment on the container.

2.2.4.2.2
How will the generation of hydrogen, oxygen, and other species affect the corrosion modes and rates of the waste package container?

As a continuation of 2.2.4.2.1, this issue specifically addresses the effect of the radiolytically generated species on the rate and mode of corrosion.

2.2.4.3
What effects will the packing materials around the waste package container have on the corrosion mechanisms and rates for the container?

This issue is intended to identify the information concerning packing material performance needed to assess container corrosion, and to re-examine the responses to issues 2.1.2 through 2.1.5.2 from that perspective to ensure completeness.

2.2.4.4
Will microbes affect corrosion of the waste package container, and if so, how?

It has been suggested that bacterial effects can result in enhanced corrosion of the container. The extent to which bacteria can survive in the underground facility during the interval of interest and the effects which such bacteria may have on container degradation must be assessed.

2.2.5
What are the anticipated physical dimensions of waste package container breach as a function of time?

This question addresses, in part, the extent to which brine contacting the waste form will be static or free-flowing. If brine surrounding the waste form is largely static, the concentration of leaching and dissolution products will build up, and solubility and perhaps auto-catalytic effects may become important.

2.2.6
What will be the physical characteristics (e.g., temperature, pressure, and flow rate) of the brine penetrating the waste package container and reaching the waste form as a function of time?

This issue is intended to account for the changes in the physical characteristics of the brine reaching the waste form as a result of interactions with the container.

2.2.7
What will be the chemical characteristics (e.g., Eh, pH and chemical constituents of the brine penetrating the waste package container and reaching the waste form as a function of time?

This issue is intended to account for the changes in chemical characteristics of the brine reaching the waste form as a result of interactions with the container.

2.2.8 How will design of the waste package container accomodate all potential natural waste package-induced conditions?

This issue is intended to draw upon the analyses developed for the preceding container-related issues in order to evaluate the performance in the repository environment of the container design selected. Factors that should be considered include, but are not restricted to, container fabrication (especially heat treatments and welding processes), and emplacement (canistering) of the waste form (if the waste form canister also serves as a long-term containment barrier).

Waste package issue 2.3 is a restatement of performance issue number 6: It is listed below as a "1st-tier" waste package specific issue because this (performance) issue is addressed only under the subject heading waste package, (it is not addressed in other technical positions or other technical disciplines).

2.3
When, how, and at what rate will radionuclides be released from the waste form?

One of the performance objectives in 10 CFR 60, (60.113(a)(1)(ii)(B)) addresses the rate at which radionuclides will be released from the engineered barrier system. This release rate will depend in part, perhaps most significantly, on the rate at which radionuclides will be released from the waste form. Further, the mechanism and extent of radionuclide retardation in both the packing material and in the geologic setting will depend on the amount and species of the radionuclides released.

2.3.1
What are the physical, chemical, and mechanical properties of the waste form, how do those properties of the waste form change with time, and how will such changes alter the ability of the waste form to contribute to the overall performance of the repository system or impact the performance of other barrier materials and properties of the site?

This issue addresses various concerns including, but not restricted to, devitrification of glass waste forms, or degradation of any waste forms due to radioactive decay or other processes prior to and during contact with brine. Effects of radioactive decay include degradation due both to radiation effects and to transmutation of radionuclides into elements which tend to destabilize the waste form.

2.3.2
What is the solubility of the waste form under the range of potential repository conditions?

The range of solubility of the waste form matrix, whether it is high level waste glass or spent fuel, must be known or estimated to assess which mode of dissolution as a function of time will control radionuclide releases.

2.3.2.1
What are the possible dissolution mechanisms of the waste form under the range of potential repository conditions?

Under the range of possible repository conditions several dissolution mechanisms may be active. For example, devitrification of the glass or oxidation of the spent fuel may result in physical failure of the waste form by cracking and spalling, or radionuclides may be leached chemically either by a solubility-limited or bulk waste form dissolution mechanism.

2.3.2.1.1
Which waste form dissolution mechanism or mechanisms are most likely?

This issue is intended to examine the dissolution mechanisms identified in the previous issue to determine the controlling mechanism as a function of waste form and time, recognizing that the controlling dissolution mechanism may vary with time.

2.3.2.1.2
What are the rates of dissolution associated with the potential waste form dissolution mechanisms?

The dissolution rates of individual radionuclides may be a function of the waste form matrix or of the solubilities of the individual radionuclides. The rate of dissolution for each radionuclide will provide the source term for near and far-field radionuclide migration determinations.

2.3.2.2
What non-radioactive dissolution products are likely to be produced from the waste form?

It will be necessary to determine the amount and nature of non-radioactive dissolution products to determine their effects on the ability of the packing materials and the geology to inhibit radionuclide migration.

2.3.2.3
What are the solubilities of the radionuclides released from the waste form?

For dissolution by leaching, the solubilities of each individual radionuclide will determine whether that radionuclide will be controlled by solubility-limited or bulk waste form dissolution.

2.3.2.4
What will be the chemical species of the radionuclides released from the waste form?

The solubility and the rate of release and migration of a radionuclide from the waste package will be a function of the chemical species of the radionuclide (e.g., oxide, nitride, ionic sub-species). This information is necessary to predict compliance with 10 CFR 60.113(a)(1)(ii)(5), concerning release from the engineered barrier system.

2.3.3
What colloids or other suspended particles will be produced from the waste form?

Several of the potential low-solubility species in radioactive wastes can form colloids or become part of other colloidal substances released from the waste form. It is necessary to account for such species in the calculation of source terms and the determination of how waste package design and performance will assure compliance with 10 CFR 60.113(a)(1)(ii)(B), concerning release from the engineered barrier system.

2.3.3.1
How may the formation of colloidal particles affect waste form degradation?

It is possible to under-predict or over-predict the rate of waste form degradation and release of radionuclide if colloid formation is neglected. It should be taken into account, therefore, in the waste package/waste form design and performance prediction.

2.3.3.2
How may radionuclides that are released from the waste form be transported in colloids or other suspended particle form?

For low-solubility species it is possible that the rate of transport through the leached waste package container out through the packing, and into the near-field, can be increased if colloids and suspended precipitates form at or near the waste form surface. The formation and transport of suspended matter containing low-solubility radio-elements should, therefore, be accounted for in waste package design and performance prediction.

2.3.4
What are the predicted ranges of residence times of a unit volume of brine in contact with a unit area of waste form as a function of time?

This question addresses the extent to which brine contacting the waste form will be migrating. If brine surrounding the waste form is largely static, the concentration of leaching and dissolution products will build up and solubility and perhaps auto-catalytic effects may become important.

For slightly soluble species, the slow diffusion and slow movement of brine around the waste form may be more important in controlling the net rate of dissolution than the rate at which substances inside the waste material reach the surface of the waste form. If the solubility is sufficiently large, the kinetics of the interaction between the solid waste constituents and the brine may dominate. These considerations should be addressed in the waste package/waste form design and performance prediction.

2.3.4.1
For spent fuel, how does the fuel rod cladding change the predicted effective residence time of a unit volume of brine in contact with a unit area of waste form?

For spent fuel the Zircaloy or stainless steel cladding may serve as an additional barrier or impediment to the contact of brine with the radioactive waste and subsequent release of radionuclides. For credit to be taken for such a barrier, the effect of cladding breaches on residence times and release rates should be considered in waste package design and performance analysis.

2.3.4.2
For reprocessed fuel, how may alterations in physical form (e.g., cracking) alter the predicted effective residence time of a unit volume of brine in contact with a unit area of waste form?

In a way analogous to spent fuel cladding, physical alterations in the reprocessed fuel waste form (e.g., cracking of borosilicate glass) could affect the predicted effective residence time. Such phenomena should be taken into account in waste package/waste form design and performance prediction.

2.3.5
How will packing, container materials (including overpacks, canisters, and any special corrosion-resistent alloys or spent fuel rod cladding, if applicable), and/or their alteration products interact with the waste form to cause its alteration and/or affect release of radionuclides?

Regardless of the initial in-situ composition of the brine in a salt repository, the brine will change in chemical characteristics as it migrates through and reacts with the waste package packing and container materials and to the surface of the waste form. Packing and container materials and reaction products that are transported with the brine to the waste form could conceivably interact with the waste form and affect the release of radionuclides from the waste form. Such effects should be accounted for in waste package design and performance prediction.

2.3.6

For spent fuel, what are the potential damage and failure mechanisms for the fuel rod cladding?

This issue deals with the extent to which spent fuel rod cladding may enhance or degrade the performance of the waste package. Regardless of whether or not DOE wishes to take credit for the cladding in waste package performance prediction, it will be necessary for NRC to determine whether the cladding has any adverse effects on waste package performance.

2.3.6.1

What is the predicted rate of failure for each of the potential failure mechanisms for spent fuel?

It is expected that the spent fuel rod cladding will be subjected to a limited number of failure mechanisms involving chemical effects such as hydriding or oxidation, mechanical effects such as fracturing due to the overloading, or synergistic effects such as stress/corrosion cracking. It is possible that to some degree the cladding may be damaged if not actually breached, during the time it is stored in spent fuel pools or elsewhere, prior to containment in a waste package for burial, or during handling. Estimates should be provided of the number of failures that may occur due to each identified failure mechanism so that this information can be factored into the determination of the release of radionuclides from the waste form.

2.3.6.2

What is the predicted size of cladding breach associated with each of the potential spent fuel cladding failure mechanisms?

The rationale for this issue is analogous to that for issue 2.2.5 for the size of breach in the waste package container, viz., the rate of leaching and dissolution of the radionuclides from the waste form may be affected by the size of the flow path.

2.3.6.3

For fuel rods with defected cladding, how will the presence of defects alter the radionuclide retention capability of the spent fuel waste form?

For a significant barrier effect to be claimed for breached cladding, it will be necessary to show to what extent the rate of release and leaching of radionuclides from the spent fuel is affected by the presence of defects of varying number, type, size, and time of occurrence.

2.3.7 How will the design of the waste form accomodate all potential natural and waste package-induced conditions?

This issue is intended to draw upon the analyses developed for the preceding waste form-related issues to ensure that all aspects of the waste form functional requirements have been considered in the waste form design and performance predictions. Design features of the waste form that should be considered include, but are not restricted to the composition of waste glass, the arrangement of spent fuel rods within the container, and any synergistic effects that may ensue due to additional materials placed within the container (e.g., steel support members or sand fill).

2.4 How and at what rates will radionuclides migrate through failed waste packages?

This issue recognizes that radionuclide release from containers may vary between general release from a uniformly failed container to a highly concentrated release from a small breach in what is effectively a point source.

2.4.1 What will be the convective flows in the waste package as a function of time?

The concerns underlying this issue have been expressed in 2.1.1, 2.3.4, and other related issues.

2.4.2 What are the transport and retardation processes important to the flux of radionuclides with time in waste package packing materials?

Depending on the choice of materials, the packing surrounding the container may have considerable influence on the nature and rate of release of certain radionuclides, in particular, by trapping or delaying radionuclides whose retardation by the adjacent geology may be uncertain. These effects are likely to be a function of both the equilibrium conditions which would result in the absorption or precipitation of the radionuclides and the kinetics of those processes. These phenomena, coupled with the brine migration rates through the packing, constitute the transport and retardation processes.

2.4.3

How will the radionuclide species (i.e., particles, colloids and solubles) change with time in the waste package?

This issue recognizes that substantial changes in such parameters as temperature, oxygen activity, and radiation field are likely to occur during the 10,000 year interval of interest, and that these changes are likely to affect the radionuclide species released from the waste packages.

2.4.4

What will be the solubility as a function of time of the species incorporating radionuclides in the vicinity of the waste package packing materials?

The rationale for this issue appears under Issues 2.4.3 and 2.3.2 above.

2.4.5

Will alpha radiation in the waste package packing materials affect chemistry and hence transport and radionuclide species identification?

The NRC staff considers that radionuclide bearing species may not necessarily behave as though they were stable isotopes. If DOE wishes to make such an assumption, it will be necessary to demonstrate its validity, perhaps through bounding analyses.

2.4.6

Will microbes affect transport in waste package packing materials? If so, how?

It has been suggested that bacterial effects can result in enhanced radionuclide transport. The extent to which bacteria can survive in the packing during the interval of interest and the effects which such bacteria may have on radionuclide speciation or on transport in the packing must be assessed.

2.5

How does the waste package design address releases of radioactive materials to unrestricted areas within the limits specified in 10 CFR 20?

It is the purpose of the regulations contained in 10 CFR 20 to limit the occupational radiation exposure of individuals to as low as is reasonably achievable. The waste package design and performance prediction should address this requirement.

2.5.1

How will the waste package shielding contribute to the maintenance of radiation doses, levels, and concentrations within the limits of 10 CFR 20?

The degree to which the waste package container contributes to the "as low as reasonably achievable" occupational exposure goal of 10 CFR 20 should be assessed as required by 10 CFR 60.131(a)(3). The amount of shielding provided will be a function of the type and thickness of the materials used in the waste package container.

2.5.2

How will the waste package design provide assurance that necessary safety functions will be carried out in the geologic repository area?

The means by which the waste package design assures that necessary safety functions are provided in the geologic repository operations area should be assessed as required by 10 CFR 60.131(b).

2.5.2.1

How will the waste package design protect against natural phenomena and environmental conditions anticipated at the geologic repository area?

The means by which the waste package design protects against natural phenomena and environmental conditions anticipated at the geologic repository area should be assessed as required by 10 CFR 60.131(b)(1).

2.5.2.2

How will the waste package design protect against the dynamic effects of equipment failure and similar events?

The means by which the waste package design protects against the dynamic effects of equipment failure and similar events should be assessed as required by 10 CFR 60.131(b)(2). Such assessment should include but not be limited to missile impacts and crane or other equipment failures that could result in a dropped package.

2.5.2.3

How will the waste package be designed to perform its safety functions during and after credible fires or explosions in the geologic repository area?

The means by which the waste package design provides assurance that the waste package structures, systems, and components important to safety perform their safety functions during and after credible fires and explosions in the geologic repository operations area should be assessed as required by 10 CFR 60.131(b)(3).

2.5.3

How will the waste package design provide protection against radiation exposures and offsite releases prior to permanent closure?

The rationale for this issue appears under Issue 2.5.

2.6

How does the design of the waste package accomodate the requirement that the waste should be retrievable at any time up to 50 years after emplacement?

The rule (10 CFR 60.111(b)) states that the geologic repository operations area shall be designed so that any of the emplaced waste could be retrieved on a rasonable schedule starting at any time up to permanent closure (which is defined as 50 years after waste emplacement operations are initiated).

The rule (10 CFR 60.135.(b)(3)) further requires that the waste packages shall be designed to maintain waste containment during transportation, emplacement and retrieval.

To accomodate this requirement, with whatever waste package design DOE proposes, it must allow for operations required to be performed on the waste package for retrievability purposes.

2.6.1

What features of the waste package container will be provided to facilitate transportation and retrievability before emplacement or retrievability from the underground facility after emplacement?

During transportation of the waste in a container from the waste processing facility to the underground facility, the container acts as a shield to protect personnel involved in the operation and serves to facilitate handling. When retrievability is required, the container is also required to provide features for operations of the waste from the underground facility to locations designated in DOE's plan for the follow-on action for the retrieved waste, such as reprocessing, repacking and/or storage. For operational personnel safety and to facilitate transportation and retrievability, the waste package container must, therefore, provide design features for such operations.

2.6.2
What features of the waste package packing will facilitate retrievability of the waste package after emplacement?

DOE's waste package design may or may not include packing. If packing is included as part of the waste package design, the presence of the packing must not cause undue delay (or negate the option) of waste retrieval after the package has been emplaced.

2.6.3
What labels or other means of identification will be provided for the waste package to facilitate retrievability?

The rule (10 CFR 60.135(b)(4)) specifically requires that a label or other means of identification be provided for each waste package. Identification of individual waste packages is a necessary part of a quality assurance plan and such identification of individual assemblies is standard in the nuclear industry.

The identification is required to maintain traceability of the waste package and its contents during the retrieval period.

2.6.3.1
How will the waste package design provide that the identification on the waste package will not impair the integrity of the waste package?

The rule (10 CFR 60.135(b)(4)) specifically requires that the identification shall not impair the integrity of the waste package. The objective of the identification is to facilitate actions required for retrieving the waste when called for. Since the waste form at retrieval time still requires the protection of the waste package container for containment, the identification must not impair the integrity of the waste package container.

2.6.3.2
How will the waste package design provide that the identification information on the waste package will be legible at least to the end of the period of retrievability?

The waste and the container come from different sources at different times. Therefore, it will be necessary to include information on the waste package container to determine if retrieval of packages is required. This information must be legible to the end of the period of retrievability.

2.6.3.3

How will the waste package design provide that each waste package identification will be consistent with the waste package's permanent written record?

Consistency of waste package identification with the waste package's records (as stated in 10 CFR 60.135(b)(4)) is required to assure that the actions taken at retrieval and after retrieval are appropriate for the wastes identified.

2.7

How will the waste package design preclude explosive, pyrophoric and chemically reactive materials?

Materials that are explosive or phyrophoric have the potential for seriously damaging waste package integrity and releasing radioactivity in an uncontrolled and unexpected manner.

Chemically reactive materials are included in 10 CFR 60.135(b) in recognition of the fact that there are other types of rapid chemical reactions which may occur in addition to the rapid oxidation reactions associated with explosions and burning of explosives and pyrophoric materials. Therefore, any chemical (for example, an active reducing agent) which could react rapidly and thereby damage a waste package's integrity is also undesirable. The NRC staff recognizes that most materials are chemically reactive if conditions (pressure, temperature, and concentrations of other chemical reactants) are appropriate. Thus, it is reasonable to consider the potential conditions that waste package materials could be expected to encounter during handling, emplacement, retrieval and long-term storage in demonstrating whether or not the waste package materials fall within this category.

2.7.1

How will the waste package design preclude free liquids in an amount that could compromise the ability of the waste package to achieve the performance objectives related to containment of HLW (because of chemical interactions or formation of pressurized vapor) or the prevention of spillage and spread of contamination in the event of waste package perforation during the period through permanent clsoure?

Free liquids, when subjected to radiation can degrade and release gases. The liquids may also vaporize because of temperatures within a waste package. These two phenomena could pressurize a waste package to the point where it would leak or explode.

2.7.2

How will the waste package design ensure that the radioactive waste will be in solid form in a sealed container?

This is one of the three criteria for HLW waste forms (10 CFR 60.135(c)). This issue is consistent with the liquid requirement. The requirement of a waste in solid form also simplifies the analysis (and verification) of chemical and physical phenomena occuring within a waste package..

2.7.3

How will the waste package design ensure that particulate waste forms will be consolidated (for example, by incorporation into an encapsulating matrix) to limit the availability and generation of particulates?

This issue is derived from one of the three criteria for HLW waste forms (10 CFR 60.135(c)). To minimize dispersibility and human exposure in the event of an accident (such as a handling accident) small radioactive particles released during an accident should be limited because they are difficult to retrieve. They are more hazardous than consolidated waste because they may be respirable. Consolidation also eliminates unnecessarily high leach rates in brine that might result from high-surface areas presented by particulates.

2.7.4

How will the waste package design ensure that either (a) all combustible radioactive waste have been reduced to a non-combustible form or (b) a fire involving the waste packages containing combustibles will not (1) compromise the integrity of other waste packages, (2) adversely affect any structures, systems, or components important to safety, or (3) compromise the ability of the underground facility to contribute to waste isolation?

This issue is derived from one of the three criteria for HLW (§60.135(c)). This requirement restricts the nature of waste forms to innoccuous forms which in case of a fire will not represent a public health and safety hazard. Combustion of waste forms has the potential of rapidly dispersing the radioactivity in the waste form and creating a hazard.

Meeting the requirement will simplify the problem of evaluation of a fire hazard and thereby facilitate the licensing activity where practical. However, the requirement also allows for demonstrating adequacy of a particular combustible waste.

2.8
What are the conditions that might affect criticality in the vicinity of the waste package?

10 CFR 60.131(b)(7) requires all systems to be designed so that criticality will be impossible unless two unlikely, independent, and concurrent or sequential changes have occurred. The waste package should be designed to ensure criticality safety under all normal and postulated accident conditions.

2.8.1
How will the waste form radionuclide inventory and the overall design (including shielding) of the waste package be controlled to ensure that criticality will not be reached during the handling and storage of waste packages during the operational phase of the repository?

The waste package design should preclude the possibility of attaining criticality due to any advertent or inadvertent mishandling.

2.8.2
By what means could actinides be concentrated in the packing materials to create a potential for criticality after emplacement of the waste packages?

To enable the NRC staff to reach the finding required by 60.131(b)(7) mentioned in 2.8 above, the staff will require an analysis showing that no transport or other processes can be reasonably expected to result in reconcentration of actinides in the packing materials in such a way as to significantly increase heating or affect criticality.

2.9 How will the design of the waste package accomodate the monitoring of the package without adversely affecting waste package integrity?

The objective of 10 CFR 60.143(a) is to establish an in-situ monitoring program to observe the performance of the waste packages in their actual repository environment and demonstrate that they conform to design and regulatory requirements.

The attributes of the type of program acceptable to NRC are discussed in a Staff Technical Position on post-emplacement monitoring.

# DRAFT SITE ISSUES FOR GEOCHEMISTRY

3.0 Geochemistry

3.1 WHAT ARE THE PRESENT GEOCHEMICAL CONDITIONS?

3.1.1 What are the present geochemical conditions of the geologic setting?.

3.1.1.1 What are the present temperature and pressure conditions in the host rock?

3.1.1.2 What is the present petrology/mineralogy/chemistry of the host rock and adjacent sedimentary units?

3.1.1.3 What is the present amount of interstitial and bound water and its chemistry in the host rock (intracrystalline and intercrystalline inclusions, hydrous minerals)?

3.1.1.4 What are the present geochemical conditions in the groundwater?

3.1.2 What is the petrology/mineralogy/chemistry of the backfill/seals/packing to be emplaced?

3.2 WHAT ARE THE CHANGES IN THE GEOCHEMICAL CONDITIONS/PROCESSES AS A RESULT OF WASTE EMPLACEMENT?

3.2.1 What are the changes in the geochemical conditions of the geologic setting?

3.2.1.1 What are the changes in temperature and pressure conditions in the host rock?

3.2.1.2 What are the changes of the petrology/mineralogy/chemistry of the host rock and adjacent sedimentary units?

3.2.1.3 What is the migration behavior of interstitial and bound water in the host rock as a result of waste emplacement?

3.2.1.4 What are the changes in the geochemical conditions in the groundwater?

3.2.2 What are the changes in the geochemical conditions of the backfill/seals/packing as a result of waste emplacement?

3.2.2.1 What are the changes in the temperature and pressure conditions in the backfill/seals/packing?

3.2.2.2 What are the changes in the petrology/mineralogy/chemistry of the backfill/seals/packing as a result of waste emplacement?

3.3 WHAT ARE THE FUTURE GEOCHEMICAL PROCESSES/CONDITIONS THAT WILL AFFECT RELEASE AND TRANSPORT OF RADIONUCLIDES TO THE ACCESSIBLE ENVIRONMENT?

3.3.1 How does solubility/concentration of radionuclides affect radionuclide release and transport?

3.3.1.1 How does precipitation/co-precipitation affect radionuclide solubility/concentration?

3.3.1.2 How does speciation affect radionuclide solubility/concentration?

3.3.1.3 How do colloids/particulates/organics affect radionuclide solubility/concentration?

3.3.2 How do backfill/seals/packing/disturbed-zone/far-field mineralogies influence radionuclide migration/retardation?

3.3.3 What is the importance of reaction and sorption kinetics on radionuclide release and transport?

3.3.4 How do redox conditions affect radionuclide speciation/migration/retardation?

3.3.5 How does gamma and alpha radiolysis affect radionuclide release and transport?

3.3.6 How do colloids/particulates affect radionuclide migration/retardation in the disturbed zone/far field?

3.3.7 How do organics and microbes affect radionuclide migration/retardation in the disturbed zone/far field?

3.3.8 How does diffusion affect radionuclide migration/retardation in the disturbed zone/far field?

DISCUSSION

Issue 3.1 covers the initial geochemical environment of the repository, i.e., the geochemical baseline for the repository. Issue 3.2 covers changes to the initial geochemical environment, which will be caused by construction of the underground facility and waste emplacement, and then changed further during heating due to decaying waste. Issue 3.3 deals with the waste package/geologic environment interactions and the transport of waste radionuclides to the accessible environment.

The rationale for each issue is described in the following discussion. In the discussion, the broadest issues, i.e., those that would appear in the first tier of a hierarchy of issues and sub-issues, are related directly to the performance issues that are listed in the Background section above. Sub-issues are related by technical argument to the issue(s) directly above them in the logic tree.

3.1 WHAT ARE THE PRESENT GEOCHEMICAL CONDITIONS?

An understanding of the present geochemical conditions is necessary in order to evaluate the suitability of a repository for containing waste and controlling the release of radionuclides from the disturbed zone to the accessible environment (performance issues 9 and 10). Adverse conditions within the far field are likely to remain unchanged after waste emplacement, whereas favorable pre-waste emplacement conditions in the disturbed zone may alter to potentially adverse conditions following waste emplacement. Since the geologic medium is considered as a possible barrier to release of radioactive waste to the accessible environment, an understanding of the present geochemical conditions is necessary to establish a baseline for prediction of geochemical conditions under typical repository conditions.

3.1.1 What are the present geochemical conditions of the geologic setting?

The geologic setting includes the bedded salt or domed salt in which the respository is constructed and the surrounding sedimentary rocks and interbeds. The geologic setting is considered to be an important barrier in geologic waste isolation. For this reason, it is necessary to understand the present geochemical conditions so that host rock behavior under repository-induced conditions can be predicted with confidence.

3.1.1.1 What are the present temperature and pressure conditions in the host rock?

Temperature and pressure are important parameters for understanding the chemical stability of the minerals in the host rock and interstitial and bound water behavior. Therefore, baseline measurements are necessary for determining the magnitude of changes for these parameters under the stressed environment induced by a repository.

3.1.1.2 What is the present petrology/mineralogy/chemistry of the host rock and adjacent sedimentary units?

The composition of the salt host rock and adjacent sedimentary units will influence the stability of a repository and the migration of radionuclides. Knowledge of the mineralogy, petrology, and chemical composition of both primary and secondary minerals in the salt and associated sedimentary rocks will lead to a better understanding of the genesis and the future geochemical stability of the geologic setting, aid in the evaluation of the effects of waste/rock interactions, and provide information for interpreting the groundwater chemistry.

3.1.1.3 What is the present amount of interstitial and bound water and its chemistry in the host rock (intracrystalline and intercrystalline inclusions, hydrous minerals)?

The amount of water available for migration to, and contact with, the waste package will affect waste package degradation and the ability of radionuclides to migrate to the accessible environment. Sources of water in the salt host rock include intracrystalline and intercrystalline brine inclusions (including pressurized brine pockets) and hydrous minerals. Water chemistry (composition, pH, redox conditions, ionic strength) influences the formation of chemical species and the migration behavior of many radionuclides. In addition, the composition of water contacting the waste packages will affect the rate of waste package corrosion. For example, waters with high amounts of magnesiu, such as may be found in brine inclusions, can cause accelerated rates of corrosion.

3.1.1.4 What are the present geochemical conditions in the groundwater?

No groundwater flow is expected in the salt host rock, but geochemical conditions of the groundwater in the adjacent sedimentary units will influence future transport of released radionuclides and give information on salt dissolution. Geochemical conditions, in particular temperature, pH, redox conditions, ionic strength, and presence of complexing ligands, determine which chemical species of radionuclides are most likely to form and determine what reactions are likely to occur. A determination of baseline values for these parameters will help in determination of a site's ability to contain waste.

3.1.2 What is the petrology/mineralogy/chemistry of the backfill/seals/packing to be emplaced?

Backfill, seals, and packing, as discussed here, refer to materials used to plug shafts, tunnels, disposal rooms, and around canisters. The large man-made cavities represent potential pathways to the accessible environment for radionuclides released from the waste package that must be blocked with engineered barriers. The petrology, mineralogy, and chemistry of the backfill, seals, and packing will influence their ability to seal these cavities and prevent water ingression and radionuclide migration.

## 3.2 WHAT ARE THE CHANGES IN THE GEOCHEMCIAL CONDITIONS/PROCESSES AS A RESULT OF WASTE EMPLACEMENT?

The geochemical conditions of the host rock salt environment will be affected by construction of the underground facility and emplacement of nuclear waste. Shaft construction may provide a pathway for overlying groundwater to enter the repository horizon and profoundly affect repository performance. During repository construction, brine pockets or dissolution features may be encountered. Thermal and pressure changes in the vicinity of the repository may alter the properties of the salt or minerals in sedimentary interbeds (i.e., shale) to the extent that stability is threatened or water is more accessible to the waste package and backfill. This in turn may affect engineering properties and the physical stability of the repository. It is important to understand potential geochemical conditions following waste emplacement so that repository performance can be assessed (performance issues 3 through 10). Both anticipated and unanticipated processes and events should be considered when evaluating this issue.

### 3.2.1 What are the changes in the geochemical conditions of the geologic setting?

Repository construction and waste emplacement will cause changes in temperature, pressure, and groundwater behavior which may affect mineral assemblages and their ability to act as barriers for waste isolation. Therefore, information on the geochemical conditions following waste emplacement is needed to determine the ability of the repository to contain waste.

#### 3.2.1.1 What are the changes in temperature and pressure conditions in the host rock?

The magnitudes of thermal and pressure gradients over time and space must be determined to understand brine migration in the salt. These parameters also significantly affect mineral alterations and groundwater chemistry. Since salt is relatively mineralogically stable at expected repository-induced temperatures, thermal effects may have greater influence on sedimentary interbeds.

#### 3.2.1.2 What are the changes of the petrology/mineralogy/chemistry of the host rock and adjacent sedimentary units?

Mineral assemblages may be affected by repository construction and changes induced by waste emplacement. Many minerals exist in metastable states and the changes in temperature, pressure, water chemistry, and/or degree of saturation may alter the stability of the minerals in a rock. These changes can influence the sorptive behavior of the salt host rock and associated sedimentary rocks and their ability to prevent water ingression and the physical stability of the repository.

3.2.1.3 What is the migration behavior of interstitial and bound water in the host rock as a result of waste emplacement?

Thermal and pressure gradients induced by waste emplacement may cause water in inclusions or hydrous minerals in the salt to migrate towards the waste package. Information on the amount of water affected, migration rates, and changes in water composition on reaching the waste package is necessary to assess the effects of brine migration on waste package degradation and migration of radionuclides.

3.2.1.4 What are the changes in the geochemical conditions in the groundwater?

This is a particularly important issue for potential salt sites. A common expectation in siting a repository in salt is that only very small quantities of water will move through the repository system. However, there are potential mechanisms for the ingression of significant amounts of groundwater which must be addressed, including transport through dissolution features and discontinuities (i.e., joints, faults) and transport through sedimentary interbeds (in bedded salt). The presence of groundwater and its chemistry may profoundly affect a salt repository's performance by influencing waste package integrity and providing transport pathways for radionulides. In addition, reactions of radionuclides in solution with components of the backfill, seals, and packing, and the disturbed-zone and far-field host rock, including adsorption and precipitation, will determine the limiting concentrations of soluble species. Geochemical conditions in the groundwater, in particular temperature, pH, redox conditions, ionic strength, and water chemistry, can be affected by repository-induced changes.

3.2.2 What are the changes in the geochemical conditions of the backfill/seals/packing as a result of waste emplacement?

Backfill, seals, and packing will be affected by physical changes induced by waste emplacement, such as changes in temperature, pressure, and degree of saturation. Changes in backfill, seals, and packing petrology, mineralogy, and chemistry may affect their stability and ability to retard radionculides by sorption or ion exchange.

3.2.2.1 What are the changes in temperature and pressure conditions in the backfill/seals/packing?

The magnitudes of thermal and pressure gradients over time and space must be determined to understand brine migration processes through the backfill, seals, and packing. These parameters also significantly affect mineral alterations and groundwater chemistry.

3.2.2.2 What are the changes in the petrology/mineralogy/chemistry of the backfill/seals/packing as a result of waste emplacement?

Mineral assemblages may be affected by repository construction and changes induced by waste emplacement. Many minerals exist in metastable states and the changes in temperature, pressure, water chemistry, and/or degree of saturation may alter the stability of minerals in the backfill, seals, and/or packing. These changes can influence the sorptive behavior of the backfill, seals, and packing and their ability to prevent water ingression and the physical stability of the repository.

## 3.3 WHAT ARE THE FUTURE GEOCHEMICAL PROCESSES/CONDITIONS THAT WILL AFFECT RELEASE AND TRANSPORT OF RADIONUCLIDES TO THE ACCESSIBLE ENVIRONMENT?

Geochemical processes and conditions at the waste package surface, in the backfill, seals, and packing, the disturbed zone, and the far field will profoundly affect the release and transport of radionuclides from the repository to the accessible environment (performance issues 6 through 10). Release involves waste package degradation and solubilization of the radionuclides in the waste form. Transport involves any mechanical or chemical process which promotes or inhibits radionuclide migration from the repository to the accessible environment. During release and transport, radionuclides will react with the groundwater, the waste container, the backfill, seals, and packing, the salt, and the surrounding rock units or interbeds, and the nature of these reactions will determine the significance and the extent of the migration of each radionuclide in the waste form. Both anticipated and unanticipatecd processes and events should be considered when evaluating this issue.

3.3.1 How does solubility/concentration of radionuclides affect radionuclide release and transport?

The release rates and concentrations of waste radionuclides in solution may be determined to a significant extent by their solubilities. Dissolution of radionuclides from the waste form is controlled by the physical characteristics of the waste form (e.g., structure and surface area); chemical and radiolytic properties of the waste form; composition, redox conditions and pH of waters; and temperature and pressure. In order to determine the concentrations of radionuclides in the disturbed zone and the far field (under different geochemical conditions) through time, their solubilities need to be determined.

3.3.1.1 How does precipitation/co-precipitation affect radionculide solubility/concentration?

Under varying geochemical conditions, radionuclides in solution may precipitate in the presence of certain inorganic ligands (e.g., carbonate, hydroxyl, sulfide). Parameters controlling precipitation include groundwater composition, rock composition, redox conditions, pH, temperature, pressure, and radionuclide concentration. Certain radionuclides may co-precipitate by substitution with non-radioactive species.

3.3.1.2 How does speciation affect radionuclide solubility/concentration?

The identities and solubilities of the solid phases and identities of the solution species likely to form under geologic conditions are needed to determine solution concentrations of radionuclides in a repository groundwater system. Different species of the same element will remain in solution in different concentrations and migrate at different rates.

3.3.1.3 How do colloids/particulates/organics affect radionuclide solubility/concentration?

Some radionuclides, especially hydrolyzable ones, may readily form colloids or pseudocolloids under certain geochemical conditions. These colloids may result from interactions with the waste package, backfill, seals, and packing, or host rock. The formation of colloidal species may affect the concentrations and thus the transport of radionuclides in solution. The presence of certain organic ligands can allow some radionuclides to form complexes and remain in solution at concentrations different than uncomplexed species.

3.3.2 How do backfill/seals/packing/disturbed-zone/far-field mineralogies influence radionuclide migration/retardation?

Chemical changes in the packing material due to temperature, pressure, and changes in saturation may affect its ability to retard mobile radionuclide species. Highly sorptive minerals in the backfill, seals, packing, and host rock may cause significant retardation of radionuclides. A good estimate of the location, volume, and accessibility of minerals along the likely flow paths is necessary to assess the effects of mineralogy on radionuclide migration and retardation.

3.3.3 What is the importance of reaction and sorption kinetics on radionuclide release and transport?

The occurrence of reactions is predicted by chemical equilibrium. However, reaction rates are generally not instantaneous as predicted by equilibrium, but are kinetically controlled (time dependent). An understanding of kinetic effects would help in predicting reaction rates and the steady state conditions expected in the repository system.

3.3.4 How do redox conditions affect radionuclide speciation/migration/retardation?

Redox conditions can be a significant determinant of radionuclide speciation, solubility, and migration. Construction of a repository will allow atmospheric oxygen to enter the repository horizon and cause oxidizing conditions. After closure, atmospheric oxygen may be consumed and conditions may eventually return to a more reducing state (neglecting radiolytic effects). However, conditions may remain oxidizing for a significant period and an oxidizing front may extend out a great distance from the repository. Host rock and backfill, seals, and packing mineralogies will also affect redox conditions.

3.3.5 How does gamma and alpha radiolysis affect radionuclide release and transport?

There is evidence that radiolysis may alter redox conditions, causing generation of hydrogen, oxygen, and other species that will affect anticipated reactions. These conditions may influence radionuclide speciation and transport. Radiolysis will also affect host rock and backfill, seals, and packing mineralogies, may cause the formation of colloids, and possibly influence the predicted reactions (e.g., anhydrite precipitation).

3.3.6 How do colloids/particulates affect radionuclide migration/retardation in the disturbed zone/far field?

Under certain geochemical conditions, certain radionuclides may form colloids, pseudocolloids, or particulates. Some colloids and particulates are potentially more mobile than aqueous species formed under the same conditions. The stability and mobility of colloids and particulates under changing geochemical conditions need to be addressed in evaluating radionuclide retardation.

3.3.7 How do organics and microbes affect radionuclide migration/retardation in the disturbed zone/far field?

Organics and microbes may be introduced into a repository in salt during construction by contamination from the surface or from the host rock itself, usually in shale interbeds. Oil and gas are known to often be associated with salt beds and domes. Radionuclide-organic complexes can have different migration behaviors than inorganic complexes, and some organic radionuclide complexes are known to migrate at significantly greater rates than predicted by laboratory measurements. The presence of certain microbes can affect the reactions that occur and reaction rates. Microbes may be especially important in redox reactions. The likelihood of significant amounts of organics or microbes being present for reacting with radionuclides and influencing their migration behavior should be addressed.

3.3.8 How does diffusion affect radionuclide migration/retardation in the disturbed zone/far field?

At relatively low groundwater velocities, chemical diffusion is the dominant process for solute transport. Diffusion is driven by a concentration gradient rather than a head gradient. If the very slow water velocity conditions expected in salt deposits exist, diffusion could be a significant process for both ingression of water to the waste package and retardation of released radionuclides.

# DRAFT SITE ISSUES

# FOR

# GEOLOGIC REPOSITORY OPERATIONS AREA DESIGN/ROCK MECHANICS

## 4.0 Geologic Repository Operations Area Design/Rock Mechanics

4.1 How is the geologic repository operations area designed to maintain radiation dose levels and concentrations of radioactive material specified in 10 CFR Part 60.111(a)?

4.1.1 What are the restricted and unrestricted areas of the geologic repository operations area?

4.1.2 What provisions are taken in the design to assure that, during normal operations, releases of radioactive material into the air in the restricted area do not exceed limits specified in 10 CFR Part 20.103?

4.1.3 What provisions are taken in the design to assure that levels of radiation and releases of radioactive materials to unrestricted areas are within the limits specified by 10 CFR Parts 20.105 and 20.106?

4.1.4 How does the design of structures, systems and components important to safety incorporate the design criteria of 10 CFR Part 60.131?

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4.1.4.2 How does design of the structures, systems and components important to safety account for protection against equipment failure, fires and explosions, accident conditions, utility failures and criticality as required by 10 CFR Part 60.131?

4.1.4.3 How does design account for instrumentation and control systems to monitor and control the behavior of structures, systems and components important to safety for normal and accident conditions as required by 10 CFR Part 60.131?

4.1.4.4 How will inspection, testing, and maintenance be accounted for in the design of structures, systems and components important to safety?

4.1.5 How are surface facilities in the geologic repository operations area designed to meet 10 CFR Part 20 and EPA requirements?

4.1.5.1 How does the design of surface facilities account for radiation control, effluent monitoring and waste treatment as required by 10 CFR Part 60.132?

4.1.6 How does the underground facility design address the requirements for flexibility of design, underground openings and rock excavation as stated in 10 CFR Part 60.133?

4.1.6.1 What are the effects of in situ stresses, anomalies, differential stresses, creep rates, differential creep rates, and temperature on construction of the underground facility and emplacement of waste?

4.1.7 How is the underground facility designed to account for possible water or gas intrusion into the geologic repository?

4.1.8 How is the underground facility ventilation system designed to restrict releases to limits specified on 10 CFR Part 60.111(a)?

4.1.9 How does the design permit implementation of a performance confirmation program as specified in Part F of 10 CFR Part 60?

4.2 How is the underground facility designed to permit retrieval of waste in accordance with the performance objectives of 10 CFR Part 60.111?

4.2.1 How does the design account for natural conditions such as in situ stresses, heterogeneities and anomalies in salt formations that affect the ability to retrieve as required by 10 CFR Part 60.111(b)?

4.2.2 How does the design account for geologic repository induced, thermal-hydrological-mechanical-chemical conditions that affect the ability to retrieve as required by 10 CFR Part 60.111(b)?

4.2.2.1 What effect does thermal loading have on creep rates, in situ stresses, heterogeneities and anomalies in the salt formation?

4.2.2.2 If spalling occurs how will it affect the ability to retrieve waste packages?

4.2.2.3 What effect will brine migration and the presence of brine in the geologic repository have on the ability to retrieve waste packages?

4.2.2.4 What effect will water (if any is present) in the underground facility have on the ability to retrieve waste packages?

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4.2.3 What effect does backfill have on the ability to retrieve (if backfill is emplaced prior to expiration of the retrieval option period)?

4.2.3.1 How will backfill (if any) be remined in order to remove the waste packages?

4.2.3.2 How will waste packages retrieval be affected by changes in backfill properties due to thermal-hydrological-mechanical-chemical processes?

4.2.4 What provisions are contained in the design to assure that, during retrieval, releases of radioactive material into the air in the restricted areas do not exceed limits specified in 10 CFR Part 20.103?

4.3 How are the underground facility component of the engineered barrier system and borehole and shaft seals designed to restrict the flow of water to the waste package?

4.3.1 How does the design incorporate the geologic and natural processes which will cause water to contact the underground facility?

4.3.1.1 How much, by what means, and from what sources is intrusion of water into the engineered barrier system anticipated?

4.3.2 How does the design incorporate the geologic repository-induced changes on the geologic setting which will cause water to contact the underground facility?

4.3.2.1 What effect does the excavation of openings have on rock movement, creep, fracturing and permeabilities in the rock adjacent to the underground facility, shafts and boreholes?

4.3.2.2 What effects do thermal gradients caused by waste emplacement have on rock movement, creep, fracturing and permeabilities in the rock adjacent to the underground facility, shafts and boreholes?

4.3.3 How will borehole and shaft seals be designed to meet the release rate requirement to the accessible environment (10 CFR Part 60.112)?

4.3.3.1 How does borehole and shaft seal design account for changes in characteristics of sealing materials?

4.3.3.2 What effect will construction of the shafts (e.g., rock damaged zone, liner effects), boreholes and in situ testing have on the ability to seal openings?

4.3.3.3 How will placement of borehole and shaft seals be controlled to ensure that the performance objective stated as 10 CFR Part 60.112 is met?

4.3.3.4 How does sealing system design account for rock movement, creep, fracturing, and groundwater chemical interaction?

4.4 How is the underground facility component of the engineered barrier syste designed to prevent the function of the waste packages from being compromised?

4.4.1 How does the design incorporate the effects of the coupled thermal-hydrological-mechanical-chemical processes on the properties of the underground facility component of the engineered barrier system?

4.4.1.1 How does the design incorporate the effects of heat and radiation from the waste packages on the hydraulic conductivity, porosity, and permeability of the underground facility component of the engineered barrier system?

4.4.1.2 How does the design incorporate the effects of groundwater flow and chemical composition of the groundwater on the properties of the underground facility component of the engineered barrier system?

4.4.1.3 How does the design incorporate the effects of changes in the in situ stress field and of creep on the properties of the underground facility component of the engineered barrier system?

4.5 How is the underground facility component of the engineered barrier system designed to control releases of radionuclides?

4.5.1 What characteristics of the underground facility component of the engineered barrier system will control releases of radionuclides?

4.5.2 How will the placement methods for the underground facility component of the engineered barrier system be controlled to ensure that the system will meet the release rate requirements as stated in 10 CFR Part 60.113?

4.5.3 What level of performance is expected for the underground facility component of the engineered barrier system in order to meet the release rate requirements stated in 10 CFR Parts 60.112 and 60.113?

4.6. How does the geologic repository design account for the effects of the disturbed zone, including borehole and shaft seals, in meeting the release rate requirements of 10 CFR 60.112?

4.6.1 How will borehole and shaft seals be designed to meet the release rate requirements to the accessible environment (10 CFR Part 60.112)?

4.6.1.1 How does borehole and shaft seal design account for changes in characteristics of sealing materials?

4.6.1.2 What effect will construction of the shafts (e.g., rock damaged zone, liner effects), boreholes and in situ testing have on the ability to seal openings?

4.6.1.3 How will placement of borehole and shaft seals be controlled to ensure that the performance objective stated as 10 CFR Part 60.112 is met?

4.6.1.4 How does the sealing system design account for rock movement, fracturing, creep, and groundwater chemical interaction?

4.6.2 How does the design incorporate the effects of thermal loading on the geomechanical properties of the rock in the disturbed zone?

Discussion

The rationale for each issue is described in the subsequent discussion. In the discussion, the broadest issues, i.e., those that would appear in the first tier of a hierachy of issues and sub-issues (logic tree) are related directly to the performace issues that are listed in the Background section above. Other issues are related by technical argument to the issue(s) directly above in the logic tree.

4.1 How is the geologic repository operations area designed to maintain radiation dose levels and concentrations of radioactive material within the limits specified in 10 CFR Part 60.111(a)?

10 CFR Part 60 contains design criteria incorporating the standards for protection against radiation (10 CFR 20) for the operational period of the repository. These include criteria for both the restricted and unrestricted areas of the geologic repository operations area. DOE should identify those structures, systems and components which are important to safety. The natural and induced geologic conditions and their effects on operation and performance of the geologic repository operations area should be considered.

4.1.1 What are the restricted and unrestricted areas of the geologic repository operations area?

To apply 10 CFR Part 20 - Standards for Protection Against Radiation, as specified in 10 CFR Part 60.111(a) and .131(a), it is necessary to determine the boundaries of the restricted and unrestricted areas based on the design for the geologic repository operations area.

4.1.2 What provisions are taken in the design to assure that, during normal operations, releases of radioactive materials into the air in the restricted area do not exceed limits specified in 10 CFR Part 20.103?

10 CFR Part 60.131 requires that the geologic repository operations area shall be designed to maintain radiation doses, levels and concentrations of radioactive material in air in restricted areas within the limits specified in 10 CFR Part 20.103. The requirement applies to the restricted area during normal operations only.

4.1.3 What provisions are taken in the design to assure that levels of radiation and releases of radioactive materials to unrestricted areas are within the limits specified by 10 CFR Parts 20.105 and .106?

10 CFR Part 60.111(a) and 60.131(a) applies limits on levels of radiation and release of radioactive material in the unrestricted areas of the geologic repository operations area by 10 CFR Parts 20.105 and 106. The design for the geologic repository operations area should identify how levels and releases will be kept below those specified in Part 20 during normal operations of the facility.

4.1.4 How does the design of structures, systems and components important to safety incorporate the design criteria of 10 CFR Part 60.131?

10 CFR Part 60.131(a) requires that the geologic operations area be designed to maintain radiation doses, levels and concentrations within the limits specified in 10 CFR Part 20. The dispersal of radioactive contamination must be monitored and controlled.

4.1.4.1 How does design of the structures, systems, and components important to safety account for natural phenomena and environmental conditions?

10 CFR Part 60.131(b) requires that structures, systems, and components important to safety be designed so that natural phenomena and environmental conditions anticipated at the geologic repository operations area will not interfere with necessary safety functions.

4.1.4.2 How does design of the structures, systems, and components important to safety protect against equipment failure, fires, and explosions, accident conditions, utility failures, and criticality as required by 10 CFR Part 60.131?

10 CFR 60.131(b) requires that the structures, systems, and components important to safety be designed to (1) withstand dynamic effects of equipment failure, (2) protect against fires and explosions, (3) be capable of responding to emergencies, (4) ensure that utility service systems can function under normal and accident conditions, and (5) ensure that nuclear criticality is not possible.

4.1.4.3 How does design account for instrumentation and control systems to monitor and control the behavior of structures, systems, and components important to safety for normal and accident conditions as required by 10 CFR Part 60.131?

10 CFR Part 60.131(b) requires that the design of structures, systems, and components important to safety be designed to include provisions for

intrumentation and control systems to monitor and control behavior over anticipated ranges for normal and accident conditions.

4.1.4.4 How will inspection, testing, and maintenance be accounted for in the design of structures systems and components important to safety?

10 CFR Part 60.131(b) requires that structures, systems, and components important to safety are designed to permit periodic inspection, testing and maintenance.

4.1.5 How are surface facilities in the geologic repository operations area designed to meet 10 CFR Part 20 and EPA requirements?

10 CFR Part 60.132 requires that the surface facilities of the geologic repository operations area are designed to ensure that EPA and 10 CFR 20 standards are met.

4.1.5.1 How does design of surface facilities account for radiation control, effluent monitoring, and waste treatment as required by 10 CFR Part 60.132?

10 CFR Part 60.132 requires that surface facilities provide for radiation and effluent control and monitoring and prevent releases exceeding the levels stated in 10 CFR 20 and the EPA standard.

4.1.6 How does the underground facility design address the requirements for flexibility of design, underground openings and rock excavation as stated in 10 CFR Part 60.133?

Underground facility design must be flexible enough to accommodate site specific conditions. Consideration must be given to construction methods and the design of underground openings to limit the potential for creating a preferential pathway for groundwater or radioactive waste migration.

4.1.6.1 What are the effects of in situ stresses, anomalies, differential stresses, creep rates, differential creep rates, and temperature on construction of the underground facility and emplacement of waste?

Natural conditions at the repository horizon must be considered to insure safe waste emplacement. The effects of natural conditions on construction may include requirements for overexcavation to allow for creep closures prior to placement, increased extraction ratio for gassy conditions and increased ventilation capacity to allow for worker and equipment efficiency. Other effects may be identified during repository development which will require design changes to accomodate safe waste emplacement. The range of probable effects resulting from natural conditions needs to be identified.

4.1.7 How is the underground facility designed to account for possible water, gas, or brime intrusions into the geologic repository?

Intrusion of water, gas, or brime may have a detrimental effect on the construction and operation of the underground facility, and therefore effect the ability of the geologic repository to meet the performance objectives of 10 CFR 60.

4.1.8 How is the underground facility ventilation system designed to restrict releases of radioactive materials to limits specified in 10 CFR Part 60.111(a)?

The underground facilities ventilation system must control the release of radioactive particulates and gases to within the limits specified in 10 CFR Part 20. 10 CFR Part 60.133(g) requires that the ventilation system function during normal and accident conditions and the ventilation of excavation and waste emplacement areas be separate.

4.1.9 How does the design permit implementation of a performance confirmation program as specified in Part F of 10 CFR Part 60?

As part of the design, a system must be developed for assessing how closely actual performance compares with the performance predicted during design. The design should allow the instrumentation system to monitor repository performance without interference from repository operations. The performance confirmation program should gather information on the response and interactions between the geologic media and waste form for comparison to baseline data and expected responses.

4.2 How is the underground facility designed to permit retrieval of waste in accordance with the performance objectives of 10 CFR Part 60.111?

As required by 10 CFR Part 60.111(b) retrieval of the waste is an option that must be maintained for a period of up to 50 years after the initiation of waste placement or until a performance confirmation is completed and accepted by NRC. The design criteria and design for the geologic repository must allow for the retrievability option as required by 10 CFR Part 60.133(c).

4.2.1 How does the design account for natural conditions such as in-situ stresses, heterogeneities and anomalies in salt formations that affect the ability to retrieve as required by 10 CFR Part 60.111(b)?

The natural conditions of salt will dictate many of the design details. The amount of fracturing, heterogeneity, anisotropic properties, anomalous zones, interbedding, ambient temperature, and other geologic conditions will affect storage room and emplacement hole dimensions, creep rates and retrieval equipment. The design criteria should address how the adverse siting conditions, if present, will affect the ability to retrieve.

4.2.2 How does the design account for geologic repository induced, thermal-hydrologic-mechanical-chemical conditions that affect the ability to retrieve as required by 10 CFR Part 60.111(b)?

The excavation and development of a geologic repository operations area results in changes in the existing natural conditions. Stress gradients will develop around the openings. As repository excavation proceeds, the stresses throughout the geologic repository area will be redistributed. Stability of the rock mass is dependent on the magnitude of the stress components, the rock mass strength, thermal loading and the orientation and geometry of the excavations. The stress conditions at retrieval will be a function of excavation techniques and excavation sequence. The effect of creep on room and hole closure and of differential creep on canister orientation must be considered. Floor heave and differential creep may change the location and orientation of the waste package. Relocating the canister prior to retrieval may be required.

The environment at the time of retrieval, (e.g., the presence of steam), will influence the type of equipment used, the configuration of geologic repository openings, ventilation requirements, and safety measures.

4.2.2.1 What effect does thermal loading have on creep rates, in situ stresses, heterogeneities and anomalies in the salt formation?

The thermal load imposed by the emplacement of waste will create a thermal gradient in the rock mass. The limits and magnitude of the gradient need to be defined along with resultant thermal expansion and stress changes.

The creep rates determined in laboratory tests and limited in situ testing are related to temperature by an exponential function. Creep rates at the elevated temperature expected at the time of retrieval could be nearly an order of magnitude above those at ambient temperature.

The thermal load may adversely impact the heterogeneities and anomalies in salt. The shear zones, gas pockets, and brine pockets in the salt formation were formed under a particular set of thermal and mechanical conditons. The changes in response to the thermal loading need to be defined to ensure stability of openings as required by 10 CFR 60.133(i).

4.2.2.2 If spalling occurs how will it affect the ability to retrieve waste packages?

Spalling may occur in the form of roof falls, pillar slabbing, or floor heave. Interbeds of clay or anhydrite may be release places in distressed zones around a repository opening. The extent of spalling will affect retrieval time, equipment, worker safety, and the ability to relocate a waste package for retrieval. The design criteria for underground openings requires that the retrievability option be maintained and the potential for rock movement be minimized as stated in 10 CFR Part 60.133(e).

4.2.2.3 What effect will brine migration and the presence of brine in the geologic repository have on the ability to retrieve waste packages?

Brine pockets within the salt formation will move under a thermal gradient toward the heat source. The quantity and condition of the collected brine in repository openings needs to be identified and controlled as required by 10 CFR 60.133 (d). The impact of brine migration on the thermal-mechanical properties of the salt formation must be considered Quantity of brine concentration may also effect waste package integrity. If brine is present and steam is produced, the effect of steam in the emplacement rooms upon retrieval should also be considered.

4.2.2.4 What effect will water (if any is present) in the underground facility have on the ability to retrieve waste packages?

Groundwater may begin to resaturate the waste emplacement rooms when they are sealed off. Retrieval would necessitate re-entry of the room. The effects of water in the emplacement rooms upon retrieval should be considered.

4.2.2.5 What effect will retrieval have on the ventilation system requirements?

Ventilation requirements during retrieval will be a function of rock temperature, backfill conditions and time allowed for precooling. Depending on the magnitude of retrieval, the ventilation capacity of the confined air circuit may need to be enlarged for retrieval. The rock temperature at various times in the retrieval period needs to be defined in terms of the ventilation capacity required for retrieval. The retrieval environment, including temperature, humidity, and air quality will directly affect the type of equipment and the measure taken to keep equipment in operation. Elevated temperatures may preclude the presence of workers leading to a need to cool repository rooms to allow men to work or for remote-controlled equipment. Temperature levels and resultant equipment requirements for retrieval need to be identified.

4.2.3 What effect does backfill have on the ability to retrieve (if backfill is emplaced prior to expiration of the retrieval option period)?

The presence of backfillmay affect all of the operations necessary to retrieve the waste. Equipment systems, ventilation systems, excavation equipment, and repository facilities will need to consider the backfill during design. Equipment and excavation systems must identify how the increased temperatures will affect their ability to retrieve. Handling and storing backfill retrieval operations should be considered in the repository design.

4.2.3.1 How will backfill be remined in order to remove the waste packages?

Remining of backfill require advanced technology to assure proper equipment operation and worker safety. Under the conditions presently expected during retrieval, remining the backfill may require a remote-controlled excavation system. The system must be sensitive to changes in waste package location and to the possibility of brine pockets in the underground facility. The system for remining the backfill and appropriate design criteria for the equipment should be identified.

4.2.3.2 How will waste package retrieval be affected by changes in backfill properties due to thermal-hydrological-mechanical-chemical processes?

The ability of the excavation equipment to remine the backfill will depend on an accurate assessment of the backfill physical properties at the time of retrieval. Groundwater resaturation, possible brine migration, consolidation, and thermal effects on the backfill may require different handling procedures at the time of retrieval than when placed. The limits of the expected changes and their effects on the retrieval systems require identification.

4.2.4 What provisions are taken in the design to assure that, during retrieval, releases of radioactive material into the air in the restricted areas do not exceed limits specified in 10 CFR Part 20.103?

The retrieval option may possibly require additional provisions if it is necessary to handle contaminated material in the underground facility caused by package failure. Consideration should be given to such problems and what effects these events would have on controlling radioactive material in the restricted area.

4.3 How are underground facility component of the engineered barrier system and borehole and shaft seals designed to restrict the flow of water to the waste package?

10 CFR 60.113 requires that the release of radionuclides from the engineered barriers to the geologic setting be gradual over a long period of time. Underground Facility design will be significantly affected by the role of the barriers in mitigating radionuclide releases.

4.3.1 How does the design incorporate the geologic and natural processes which will cause water to contact the underground facility?

Salt is by nature a material with fracture healing properties. However, fracturing can occur which allows for the introduction of fresh water from overlying aquifers into the salt horizon. All factors should be considered in identifying the natural geologic factors that could cause water to enter the underground facility.

4.3.1.1 How much, by what means, and from what sources is intrusion of water into the engineered barrier system anticipated?

The greatest risk for a repository in salt is the potential for dissolution of the host salt rock and underground facility as a consequent of water ingress.

Intrusion of water into the engineered barrier system can be gradual or sudden and occur in any quantity. Sources of water intrusion could include unidentified boreholes, brine and/or gas pockets, dissolution zones, and groundwater. Potential water intrusions and their impact on geologic repository operations should be addressed.

4.3.2 How does the design incorporate the geologic repository-induced changes on the geologic setting which will cause water to contact the underground facility?

High priority should be assigned in the design activities to maintain appropriate seperation between salt and ground water flow. Excavation of a geologic repository, applied thermal loads, and the construction of vertical shafts and boreholes may enhance the flow of groundwater into the repository system. Changes in the natural conditions which may contribute to groundwater inflow should be identified and their impacts assessed.

4.3.2.1 What effect does the excavation of geologic repository openings have on rock movement or fracturing and permeabilities in the rock adjacent to the underground facility, shafts and boreholes?

The excavation of geologic repository openings will change the in situ stress conditions in the geologic repository operations area and surrounding strata. In the repository horizon little fracturing of pure salt will be expected. However, in surrounding strata the change in stress may create fractures and open existing fractures thus enhancing permeability. In addition, the intersection of anomolous zones in salt may create a high permeability pathway. Increased permeability and its effect on inflows need to be identified.

4.3.2.2 What effects do thermal gradients caused by waste emplacement have on rock movement or fracturing and permeabilities in the rock adjacent to the underground facility, shafts and boreholes?

The response of the underground facility and geologic setting to thermal loads should be defined in terms of fracture frequency and fracture opening. Expansion of geologic materials may initially close some fractures. Subsequent cooling may result in the realization of some unrecoverable strains and resultant permeability enhancement. The effects of thermal loading on fractures in the underground facility and on brine and gas pockets and interbeds in the geologic setting must be addressed, as required by 10 CFR Part 60.133(i), to assess how water could contact the engineered barrier system.

4.3.3 How will borehole and shaft seals be designed to meet the release rate requirements to the accessible environment (10 CFR Part 60.112)?

Construction of shafts and boreholes in salt alters the geologic setting and can create potential pathways for groundwater flow and migration of radionuclides. Since these pathways could adversely affect the isolation capabilities of the repository, the NRC has required in 10 CFR Part 60.134(a) that boreholes and shafts be sealed at permanent closure of the facility. Seal system characteristics should be based on the performance DOE will require of the seal system.

4.3.3.1 How does borehole and shaft seal design account for changes in characteristics of sealing materials?

The compatibility of the physical and chemical characteristics of the seal material to the salt and other evaporite strata is an important consideration in seal design. Aspects of the geologic setting should not have a detrimental affect on the integrity of the seal material. If the seal is not designed properly, salt dissolution could occur or seal material set-up time may be retarded due to infiltration of brine. Incompatability could result in seal deterioration by chemical attack causing seal system failure. Differential creep could cause shearing of the seal system. Therefore, to meet the requirements of 10 CFR Part 60.134(b), the effect of the geologic setting on seal properties must be addressed.

4.3.3.2 What effect will construction of the shafts (e.g., rock damaged zone, liner effects), boreholes and in situ testing have on the ability to seal openings?

Construction of shafts, borehole drilling, and exploratory testing will change the rock characteristics surrounding the openings. Potential effects are rock damage by excavation and stress redistribution around the opening. The effect of these phenomena on the ability to seal the openings should be assessed.

4.3.3.3 How will placement of borehole and shaft seals be controlled to ensure that the performance objective stated as 10 CFR Part 60.112?

The placement techniques used in sealing shafts and boreholes could be a controlling factor in seal performance. Reliability must be obtained in the methods and equipment used to install the seal materials. The reproducibility of results using these methods and equipment must be demonstrated, through field testing of emplacement methods and monitoring the performance of the emplaced seals.

4.3.3.4 How does the sealing system design account for rock movement, fracturing, creep, and groundwater chemical interaction?

Rock mass instabilities could cause shearing of the seal system in shafts and boreholes. Effects of deformation on the seal materials and seal system should be assessed.

The compatibility of the chemical characteristics of the seal material, the groundwater, and the host rock is an important consideration in seal design. Incompatibility could result in seal deterioration by chemical attack which could result in failure of the seal system.

4.4 How is the underground facility component of the engineered barrier system designed to prevent the function of the waste packages from being compromised?

The engineered barrier system includes the material surrounding the waste package. How water moves through the part of the engineered barrier system surrounding the waste package will affect the performance of the waste package and therefore, release rates from the geologic repository.

4.4.1 How does the design incorporate the effects of coupled thermal-hydrological-mechanical-chemical processes on the properties of the underground facility component of the engineered barrier system?

Changes to the engineered barrier system components will occur due to the combined processes caused by waste emplacement. The impact of the anticipated changes on the barriers must be addressed in the design as required by 10 CFR Part 60.113.

4.4.1.1 How does the design incorporate the effects of heat and radiation from the waste package on the hydraulic conductivity, porosity, and permeability of the underground facility component of the engineered barrier system?

Heat from the waste packages will increase in temperature of the surrounding material. The material temperature will increase to a maximum and then gradually decrease. The effects of thermal loading on the hydrologic characteristics of the underground facility must be assessed.

Temperature variations may also change the state of stress in the underground facility. The effects of stress on the hydrologic characteristics of the underground facility must addressed. Radiation from the waste package can adversely affect the properties of the underground facility. Changes in characteristics could cause release rates of radionuclides through the underground facility which exceed those specified in : CFR 60.113.

4.4.1.2 How does the design incorporate the effects of groundwater flow and the chemical composition of the groundwater on the properties of the undergrour facility component of the engineered barrier system?

Channeling in the underground facility from groundwater flow in the underground facility after permanent closure could affect the engineered barrier system performance by allowing more water to contact the waste package. This may result in greater releases of radionuclides through the engineered barrier system than was originally designed for. Alterations due to chemical interactions with the groundwater could adversely affect the performance of the underground facility.

4.4.1.3 How does the design incorporate the affects of change in the in situ stress field and of creep on the properties of the underground facility component of the engineered barrier system?

Changes in the in situ stress field and the effects of creep may adversely affect the properties of the underground facility component of the engineered barrier system. The impact of changes on the properties of backfill should be addressed in the design as required by 10 CFR Part 60.113.

4.5 How is the underground facility component of the engineered barrier system designed to control releases of radionuclides?

As stated in 10 CFR Part 60.113, the performance objectives of the engineered barriers are to limit the radionuclide release from a geologic repository. Before a license can be granted, there must be reasonable assurance that these objectives will be met.

4.5.1 What characteristics of the underground facility component of the engineered barrier system will control releases of radionuclides?

To comply with the performance objectives for the engineered barrier system as stated in 10 CFR Part 60.112 and 60.113, it will be necessary to determine the characteristics of the materials used in the barriers. It should be shown how these characteristics will limit releases of radionuclides.

4.5.2 How will placement methods for the underground facility component of the engineered barrier system be controlled to ensure that the system will meet the release rate requirements as stated in 10 CFR Part 60.113?

Placement of engineered barrier system components can be a controlling factor in their performance. Proper control of placement must be maintained to assure the expected in situ characteristics of the engineered barrier system components will meet the performance objective of 10 CFR Part 60.113.

4.5.3 What level of performance is expected for the underground facility component of the engineered barrier system in order to meet the release rate requirements stated in 10 CFR Parts 60.112 and 60.113?

Because performance of the engineered barrier system is based on meeting the EPA standard, it is important to establish what the performance levels will be expected for each engineered barrier system component. By establishing what is expected with respect to performance, design criteria can be developed to meet those objectives.

4.6 How does the geologic repository design account for the effects of the disturbed zone, including borehole and shaft seals, in meeting the release rate requirements of 10 CFR 60.112?

After permanent closure, the geologic repository operations area will induce changes in the host rock. The radial extent to which these changes affect geologic repository performance is called the disturbed zone. To predict releases to the accessible environment, it is important to know the mechanism and rate at which radionuclides will be released from the disturbed zone.

4.6.1 How will borehole and shaft seals be designed to meet the release rate requirements to the accessible environment (10 CFR Part 60.112)?

Construction of shafts and boreholes in salt alters the geologic setting and can create potential pathways for groundwater flow and migration of radionuclides. Since these pathways could adversely affect the isolation capabilities of the repository, the NRC has required in 10 CFR Part 60.134(a) that boreholes and shafts be sealed at permanent closure of the facility. Seal system characteristics should be based on the performance DOE will require of the seal system.

4.6.1.1 How does borehole and shaft seal design account for changes in characteristics of sealing materials?

The compatibility of the physical and chemical characteristics of the seal material to the salt and other evaporite strata is an important consideration in seal design.

Aspects of the geologic setting should not have a detrimental affect on the integrity of the seal material. If the seal is not designed properly salt dissolutioning could occur or seal material set-up time could be retarded due to infiltration of brine. Incompatibility could result in seal deterioration by chemical attack causing seal system fracture. Differential creep could cause shearing of the seal system. Therefore, to meet the requirements of 10 CFR Part 60.134(b), the effect of the geologic setting on seal properties must be addressed.

4.6.1.2 What effect will construction of the shafts (e.g., rock damaged zone, liner effects), boreholes and in situ testing have on the ability to seal openings?

Construction of shafts, borehole drilling, and exploratory testing will change the rock characteristics surrounding the openings. Potential effects are rock damage by excavation and stress redistribution around the opening. The effect of these phenomena on the ability to seal the openings should be assessed.

4.6.1.3 How will placement of borehole and shaft seals be controlled to ensure that the performance objective stated as 10 CFR Part 60.112.?

The placement techniques used in sealing shafts and boreholes could be a controlling factor in seal performance. Reliability must be obtained in the methods and equipment used to install the seal materials. The reproducibility of results using these methods and equipment must be demonstrated, through field testing of emplacement methods and monitoring the performance of the emplaced seals.

4.6.1.4 How does the sealing system design account for rock movement, fracturing, creep, and groundwater chemical interaction?

Rock mass instabilities and creep could cause shearing of the seal system in shafts and boreholes. Effects of deformation on the seal materials and seal system should be assessed.

The compatibility of the chemical characteristics of the seal material, the groundwater, and the host rock is an important consideration in seal design. Incompatibility could result in seal deterioration by chemical attack which could result in failure of the seal system and dissolutioning of the salt formation.

4.6.2 How does the design incorporate the effects of thermal loading on the geomechanical properties of the rock in disturbed zone?

Thermal loading caused by the emplacement of waste in the repository will change the geomechanical properties of the surrounding rock. The amount and significance of these changes need to be assessed.

# DRAFT SITE ISSUES FOR GEOLOGY/GEOPHYSICS

5.0 The Geologic System

5.1. What is the present nature of the geologic system?

5.1.1. What is the present nature of the geomorphic system?

5.1.1.1. What are the characteristics of the physiographic province, physiographic/geomorphic units and geomorphic features of the geologic system?

5.1.1.2. What are the present geomorphic processes and rates of these processes within the geologic system?

5.1.1.2.1. What are the erosional/denudation rates and mechanisms operating in the geologic system?

5.1.1.2.2. What are the present rates of dissolutioning of the domes?

5.1.1.2.3. What is the nature of uncomformities in the geologic record and how might these alter calculations of geomorphic processes?

5.1.1.3. What were the nature and rates of paleogeomorphic processes within the geologic system?

5.1.1.3.1. What was the climatic regime during the Quaternary?

5.1.1.3.2. What is the nature and rate of dome dissolutioning as calculated by:
A) Caprock thickness
B) Overdome sediment thickness
C) Amount of overdome collapse.

5.1.1.3.3. What is the history of Quaternary stream terrace development?

5.1.1.3.4. What was the nature and extent of chemical weathering during the Quaternary?

5.1.1.4. What are the relationships between the geomorphic features and structural features in the geologic system?

5.1.1.4.1. What is the relationship between stream drainage patterns and active and inactive structural features?

5.1.1.4.2. What is the nature and rate of widening of Cypress Creek over the dome?

5.1.2. What is the stratigraphy within the geologic system?

5.1.2.1. What is the geologic history?

5.1.2.1.1. What is the history of development of the "anomalous" sand at Vacherie Dome?

5.1.2.2. What are the three-dimensional geometries of the stratigraphic units?

5.1.2.2.1. What is the stratigraphy of the geologic units surrounding the dome?

5.1.2.2.2. What is the shape of the dome?

5.1.2.2.3. What is the areal extent of salt at the proposed repository level?

5.1.2.2.4. What is the nature of the salt/caprock contact?

5.1.2.2.5. What is the nature of the contact of the dome and the adjacent stratigraphic units?

5.1.2.2.6. How does caprock thickness vary?

5.1.2.3. What are the properties of the stratigraphic units?

5.1.2.3.1. What is the amount of non-salt material in the dome, and how and where is this material incorporated into the dome?

5.1.2.3.2. What are the static, dynamic and index properties of the overdome materials, the caprock and the salt stock?

5.1.2.3.3. What are the mineralogic variations in the caprock?

5.1.3. What is the present nature of the structural/tectonic system?

5.1.3.1. What are the structural features?

5.1.3.1.1. What are the structural features related to halokinesis?

5.1.3.1.2. What is the nature and distribution of lineaments and their relation with known structural features?

5.1.3.1.3. What is the relation between overdome faults, caprock faults and anomalous zones or shear zones within the salt stock?

5.1.3.1.4. What is the nature and vertical and lateral extent of overdome faults?

5.1.3.1.5. What is the nature of saddle faults in the Vacherie Dome geologic system?

5.1.3.2. What are the structural characteristics of the rock units, and how do these characteristics vary?

5.1.3.3. What geophysical anomalies exist in the geologic system, and can any structural features, including but not limited to depth to basement, be identified or defined geophysically?

5.1.3.3.1. What is the relation between structural features, lineaments and geophysical anomalies?

5.1.3.4. What is the magnitude, orientation, and spatial variation of the stress field within the geologic system?

5.1.3.4.1. What is the stress field at the proposed repository level?

5.1.3.4.2. What are the variations from the local stress field within both internal and peripheral anomalous zones?

5.1.3.5. What is the possibility that undetected structural features exist in the geologic system?

5.1.3.5.1. What is the potential for undetected overdome, deep-seated or basement faulting?

5.1.3.6. What are the absolute and relative ages of the structural features?

5.1.3.6.1. What is the age of overdome faults, the F-7 Fault and the F-9 Faults?

5.1.3.7. What has been the nature and rate of deformation, whether continuous or disruptive, up to and including the present?

5.1.3.7.1. What was the rate of diapirism during the Quaternary?

5.1.3.7.2. What was the rate and extent of spine growth during the Quaternary?

5.1.3.8. What regional tectonic models explain the structural features, nature and rates of deformation, and the geometric, mechanical, and age relationships between the structural features?

5.1.3.8.1. How do the tectonic models explain salt diapirs and their related structural features such as anomalous zones, shear zones, faults, caprock fracturing and variations in caprock thickness?

5.1.3.8.2. What are the characteristics of the closed topographic depressions over Cypress Creek Dome and adjacent to Richton Dome?

5.1.3.9. What plate tectonic models can account for the current tectonic system?

5.1.4. What are the nature and rates of seismic activity that have occurred and are occurring in the geologic setting?

5.1.4.1. What is the seismic history of the geologic setting?

5.1.4.2. What were the effects of the historic seismic events?

5.1.4.3. What seismic velocity models have been used for the instrumentally-located earthquakes?

5.1.4.4. What is the nature of seismic source areas and seismogenic structures that are of concern to the geologic repository operations area?

5.1.4.4.1. What is the potential that these structural features are seismogenic;
A) the Pickens-Gilberton Fault System, B) the Phillips Fault zone, C) the F-7 and F-9 Faults, D) the Mobile Graben, E) the Jackson Fault, F) the Maxie-Pistol Ridge Fault, G) the Payne Fault?

5.1.4.4.2. What is the southern extent of the New Madrid Fault System, and is this system potentially seismogenic?

5.1.4.5. What are the known source mechanisms of earthquakes that have affected the geologic setting?

5.1.4.6. What datable evidence of large earthquakes such as surface ruptures or sand boils, exists within the geologic system?

5.1.4.7. What is the calculated earthquake recurrence rate, determined from the historical record, in the geologic setting?

5.1.4.8. What variations are there in recurrence rates among regional seismic sources and structures?

5.1.4.9. What are the maximum credible earthquakes that can be attributed to the seismogenic structures or zones expected to affect the geologic system?

5.1.5. What is the nature of natural resources (excluding water) within the geologic setting?

5.1.5.1. What are the types, distribution and economic classification of natural resources that could be present within the geologic setting?

5.1.5.1.1. What is the potential for hydrocarbon resources, lignite or sulfur to be present near the domes?

5.1.5.1.2. What is the potential for the salt within the domes of being or becoming an economic resource?

5.1.5.1.3. What is the potential of the domes being or becoming an economically viable non-nuclear storage facility?

5.1.5.2. What potential extraction methods could be used to economically recover these resources?

5.1.5.3. What are the locations and characteristics of boreholes, mines and surface workings?

5.1.5.3.1. What are the locations and depths of sulfur exploration wells?

5.1.5.3.2. What borehole completion procedures were used?

5.1.5.3.3. What are well production histories?

5.1.5.3.4. What are the locations and

characteristics of brine injection or disposal wells and waste storage wells?

5.1.5.4. What is the nature of fluids that have been injected/withdrawn and the rates at which this has been occurring?

5.1.5.4.1. What is the nature and extent of fluid waste injection wells in the geologic system?

5.1.5.5. Is the geologic system suitabile for fluid injection?

5.2. What are the types, probabilities and nature of natural future changes that would modify the nature and rates of geologic processes?

5.2.1. What are the types, probabilities and nature of future natural changes that would modify the rates and processes of the geomorphic system?

5.2.1.1. What climatic changes could modify the geomorphic rates and processes?

5.2.1.2. What future geomorphic events could alter the geomorphic processes and rates of those processes?

5.2.1.2.1. What is the potential that dissolution-related subsidence would alter stream flow patterns and/or create surface water impoundments?

5.2.1.2.2. What is the potential that glaciation or glacial melting would change erosional processes?

5.2.1.3. What tectonic, seismic or volcanic processes could alter the geomorphic rates and processes?

5.2.2. What are the types, probabilities and nature or future natural changes that would modify the rates and processes of the stratigraphic system?

5.2.3. What future natural changes could modify the tectonic processes or rates of deformation, and what is the probability that these events could occur?

5.2.3.1. What changes in the tectonic model or tectonic processes can be predicted based on the plate tectonic model?

5.2.3.2. What types of major climatic change could affect the tectonic processes or the rates of these processes?

5.2.3.2.1. What is the potential for glacial-induced sea level changes to alter regional tectonic rates?

5.2.3.3. What types of igneous processes or events could lead to changes in the tectonic processes, or the rates of these processes?

5.2.4. What are the types, probabilities and nature of future natural changes that could modify seismic processes or the rates of seismic processes?

5.3. What are the types, probabilities and nature of human-induced changes (excepting repository-induced changes) that would modify the geologic processes or their rates within the geologic system?

5.3.1. What are the types, probabilities and nature of future human-induced changes that could modify the geomorphic processes and their rates?

5.3.1.1. What is the potential for CO2-induced climatic changes to modify the geomorphic rates and processes?

5.3.1.2. What is the potential for irrigation, flood plain occupation or flood plain modification to modify the geomorphic processes and their rates?

5.3.1.3. What is the potential for exploration, mining, fluid injection or fluid withdrawal to modify geomorphic processes and their rates?

5.3.2. What are the types, probabilities and nature of human-induced changes that could modify sedimentary rates and processes?

5.3.3. What are the types, probabilities and nature of future human-induced changes that could modify tectonic processes or the rates of those processes?

5.3.3.1. What are the types, nature and probability that fluid injection or withdrawal could change the tectonic processes, or the rates of those processes?

5.3.3.2. What are types, nature and probability that irrigation, flood plain occupation or flood plain modification could change tectonic processes, or the rates of those processes?

5.3.3.3. What is the probability that exploration or mining activities could modify the tectonic processes, or the rates of those processes?

5.3.4. What are the types, probabilities and nature of human-induced changes that could modify the seismic rates and processes?

5.3.4.1. What is the nature of human activities that could induce seismic activity?

5.4. What are the types, probabilities and nature of repository-induced changes that would modify the geologic system?

5.4.1. What are the types, probabilities and nature of repository-induced changes that could modify the geomorphic rates and processes?

5.4.1.1 What is the type, probability and nature of change in geomorphic rates and processes that will directly result from repository characterization, construction, operation and closure?

5.4.1.2 What is the type, probability and nature of change in geomorphic rates and processes that will result from indirect repository-induced changes?

5.4.1.2.1. What is the probability that repository-induced stress will either induce dissolutioning or change the rate at which it is occurring?

5.4.2. What is the type, probability and nature of repository thermal change that could modify mineral stability?

5.4.2.1. What mineralogic changes will occur in the caprock as a function of waste emplacement?

5.4.3. What are the types, probabilities and nature of repository-induced changes that could modify the tectonic processes, or the rates of those processes?

5.4.3.1. What is the type, probability and nature of change in tectonic rates and processes resulting from repository-induced thermal-hydrological-mechanical-chemical loading?

5.4.3.1.1. What is the potential for repository loading to alter diapiric rates?

5.4.3.2 What is the type, probability and nature of change in the tectonic rates and processes induced by site characterization and repository construction?

5.4.4. What are the types, probabilites and nature of repository-induced changes that could modify the seismic rates and processes?

5.5. What are the future effects on the geologic system resulting from natural changes?

5.5.1. What are the future effects on the geologic system resulting from natural changes in the geomorphic system ?

5.5.1.1. What are the future effects on the geologic system if the geomorphic rates and processes remain constant?

5.5.1.2. What will be the effects on the geologic system if the geomorphic rates and processes are modified by natural induced activities?

5.5.2. What are the future effects on the geologic system resulting from natural changes to the sedimentary processes?

5.5.2.1 What are the future effects on the geologic system if volcanism occurs?

5.5.3. What are the future effects on the geologic system resulting from natural changes to the tectonic processes and the rates of those processes?

5.5.3.1. How would the geologic system change if the tectonic processes and rates of deformation remain the same?

5.5.3.2. How would the geologic system change as a result of a change in plate tectonic processes?

5.5.3.3. How would the geologic system change as a result of a major climatic shift affecting the tectonic processes or rates of deformation?

5.5.3.4. How would the geologic system change as a result of geomorphic processes or events affecting the tectonic processes or rates of deformation?

5.5.3.5. How would the geologic system change as a result of igneous processes or events affecting the tectonic system?

5.5.4. What are the future effects of seismic activity within the geologic system?

5.5.4.1. What is the maximum expected ground motion in rock at the geologic repository operations area resulting from the maximum credible earthquakes, examined as a function of depth to at least the depth of the underground facility?

5.5.4.2. What are the postulated catatrophic coseismic events, such as landslides, liquefaction or ground rupture that could affect the geologic repository?

5.5.4.2.1. Are the sediments over Cypress Creek Dome subject to liquifaction?

5.5.4.3 What are the postulated effects on the seismic system that would result from a change in the tectonic rates and process?

5.6. What are the future effects on geology resulting from human-induced changes within the geologic setting?

5.6.1. What are the future effects on the geologic system resulting from human-induced changes to the geomorphic system?

5.6.1.1. What are the effects on the geomorphic system resulting from increase in the $CO_2$ levels in the atmosphere?

5.6.1.2. What other effects on the geologic system due to human-induced changes to the geomorphic processes can be projected?

5.6.2. What are the future effects on the geologic system resulting from human-induced changes to the stratigraphic setting?

5.6.3. What are the future effects on the geologic system resulting from human-induced changes to the tectonic processes and rates of those processes?

5.6.3.1. What are the future effects on the geologic system resulting from changed tectonic processes due to fluid injection or withdrawal?

5.6.3.2. What are the future effects on the geologic system from flood plain occupation/modification or irrigation modifying the tectonic system?

5.6.3.3. What are the future effects on the geologic system resulting from exploration or mining activities modifying the tectonic system?

5.6.4. What is the ground motion associated with human-induced seismicity as a function of depth at least to the depth of the underground facility?

5.7. What are the future effects on the geologic system resulting from repository-induced changes?

5.7.1. What are the future effects on the geologic system resulting from repository-induced changes to the geomorphic system?

5.7.1.1. What are the direct effects on the geomorphic system resulting from repository characterization, construction, operation and closure?

5.7.1.2. What are the predicted secondary effects on the geomorphic system due to induced stress on the tectonic and hydrologic system?

5.7.2. What are the future significant effects on mineral stability resulting from repository-related thermal loading?

5.7.3. What are the future effects on the geologic system resulting from repository-induced changes to the tectonic system?

5.7.3.1. What are the future effects on the geologic system resulting from waste-related thermal-mechanical-chemical loading?

5.7.3.2. What are the future effects on the geologic system resulting from site characterization and construction activities?

5.7.4. What is the ground motion associated with repository-induced seismicity, as a function of depth, at least to the depth of the underground facility?

DISCUSSION

5.0 The Geologic System

5.1 What is the present nature of the geologic system?

As defined in 10 CFR 60, the geologic setting encompasses the geologic, hydrologic, and geochemical systems of the region in which the geologic repository operations area is to be located. The geologic system is subsequently defined as the combination of all geologic features and processes within the geologic setting, and specifically includes the sub-disciplines of geomorphology, stratigraphy, structural geology and tectonices, seismicity, and natural resource evaluation. The term "nature of the system" will be used to denote the features, processes, and rates of those processes which make up the geologic setting. It is also noteworthy that the geographic boundaries of the geologic system will vary from one sub-discipline to the next. By definition, the geologic issues do not address the performance issues directly. Information regarding the geologic system is, however, fundamental to the evaluation of all performance issues by other disciplines.

5.1.1 What is the present nature of the geomorphic system?

The investigation of geomorphology provides evidence of the geomorphic processes and features which may affect the geologic repository as weel as the nature and age of tectonic features that could compromise the ability of the host rock to isolate waste. Certain geomorphic features are highly important for long term waste isolation, i.e., dissolution features and evidence of tectonic activity. The geomorphic features and processes shown to be important in the operational phase will serve as input to the design requirements and therefore provide information primarily relevent to performance issue 1. Geomorpology issues also provide input into performance issues 2,3,9,10 and 11.

The definition of geomorphology as stated by the American Geologic Institute Glossary of Geology, will be used "... the study of the classification, description, nature, origin, and development of present landforms and their relationships to underlying structures, and of the history of geologic changes as recorded by these surface features." The identification and description of geomorphic processes and features will provide evidence of the nature and age of tectonic features which could affect the ability of the host rock to isolate waste. Certain geomorphic features are especially important for long term waste isolation, such as dissolution features and evidence of tectonic activity. Geomorphic effects may alter the operational and closure design requirements (performance issue 1), in addition to providing information relevant to the evaluation of performance issues 2,3, and 9 to 11.

5.1.1.1. What are the characteristics of the physiographic province, physiographic/geomorphic units and geomorphic features of the geologic system?

As they are a reflection of both past and present natural conditions, an understanding of the nature of the physiographic province and the geomorphic units and features provides pertinent information for establishing design criteria, as well as providing the basis for determining the relationship between gromorphology and other disciplines.

5.1.1.2. What are the present geomorphic processes and rates of these processes within the geologic system?

Establishing the nature and rates of the present geomorphic processes, such as erosion and mass wasting, is the first step toward projecting their future effect on the geologic repository. This information will be used for determining whether potential pathways for the release of radionuclides exist or could be created, evaluating disruptive scenarios, and helping to establish suitable design criteria.

5.1.1.2.1. What are the erosional/denudation rates and mechanisms operating in the geologic system?

5.1.1.2.2. What are the present rates of dissolutioning of the domes?

5.1.1.2.3. What is the nature of unconformities in the geologic record and how might these alter calculations of geomorphic processes?

5.1.1.3. What were the nature and rates of paleogeomorphic processes within the geologic system?

The Quarternary record is the primary basis for projecting geomorphic rates and processes. In addition, the Quaternary and pre-Quaternary processes may have produced features which represent potential flow/transport pathways. This information, therefore, ties back into the design issues and issues 3, 8, 9, 10 and 11.

5.1.1.3.1. What was the climatic regime during the Quaternary?

5.1.1.3.2. What is the nature and rate of dome dissolutioning as calculated by:
a) Caprock thickness
b) Overdome sediment thickness
c) Amount of overdome collapse

5.1.1.3.3. What is the history of Quaternary stream terrace development?

5.1.1.3.4. What is the nature and extent of chemical weathering during the Quaternary?

5.1.1.4. <u>What are the relationships between the geomorphic features and structural features in the geologic system?</u>

The surficial expression of structural features is dependent on the rates and types of geomorphic processes acting within the setting. Understanding this relationship will aid in detecting structural features that could be a potential pathway for radionuclide migration as well as providing a better understanding of the basic geologic structures.

5.1.1.4.1. <u>What is the relationship between stream drainage patterns and active and inactive structural features?</u>

5.1.1.4.2. <u>What is the nature and rate of widening of Cypress Creek over the dome?</u>

5.1.2. <u>What is the stratigraphy within the geologic system?</u>

The term stratigraphy is here used in a manner that is broader than the American Geological Institute <u>Glossary of Geology</u> definition in that it includes volcanic depositional processes which could contribute to the stratigraphic record. It does not, however, include the addition of surficial deposits through geomorphic processes. The principle concern of stratigraphy is to insure that a host rock of sufficient depth, thickness, and lateral extent exists in which a HLW repository can be located. Description of the geometric relationships and properties of the various stratigraphic units provides the basic foundation for determining ground water flow and engineering and waste package design parameters. The description of the stratigraphic units is particularly important, since it includes not only the stratigraphic features, but also the sedimentary processes and rates of those processes. A good description of the stratigraphy will aid in the evaluation of performance issues 1 to 3 and 6 to 11.

5.1.2.1. <u>What is the geologic history?</u>

A presentation of the geologic history will permit the individual stratigraphic units to be placed in a framework of sedimentologic processes and rates. It should be noted that, in the context of this document, depositional events associated with volcanic processes also comprise a portion of the stratigraphic record. One of the primary goals of establishing the geologic history is to present a clear relationship between rock stratigraphic, hydrostratigraphic, lithotectonic, and engineering stratigraphic units and their properties. In this way, the information needs of performance issues 1 to 3 and 9 to 11 can be addressed.

5.1.2.1.1. <u>What is the history of development of the "anomalous" sand at Vacharie Dome?</u>

5.1.2.2. <u>What are the three-dimensional geometries of the stratigraphic units</u>

Vertical thickness, lateral extent, lithologic variation within each stratigraphic unit and unconformities between those units represent the basic stratigraphic information. Understanding these relationships and their associated uncertainties provides information regarding the nature and rates of sedimentologic processes which have acted on the geologic setting. The entire stratigraphic record is of concern, either in helping to solve flow/transport problems or helping determine design criteria. The Quaternary record, however, also helps provide information on potential tectonic events which could modify the setting.

5.1.2.2.1. What is the stratigraphy of the geologic units surrounding the dome?

5.1.2.2.2. What is the shape of the dome?

5.1.2.2.3. What is the areal extent of salt at the proposed repository level?

5.1.2.2.4. What is the nature of the salt/caprock contact?

5.1.2.2.5. What is the nature of the contact of the dome and the adjacent stratigraphic units?

5.1.2.2.6. How does caprock thickness vary?

5.1.2.3. What are the properties of the stratigraphic units?

Characterization of the stratigraphic units includes an appraisal of the physical and chemical properties of each unit and the spatial variation of these properties. This includes the mineralogy and petrology of the main units, their interbeds and joint fillings, their static, dynamic and index properties, the range of physical and chemical conditions under which the mineral assemblages remain stable and the variations of the properties. In as much as these characteristics are the basis for design considerations and ground water flow modeling studies, they are responsive to the information needs of all performance issues.

5.1.2.3.1. What is the amount of non-salt material in the dome, and how and where is this material incorporated into the dome?

5.1.2.3.2. What are the static, dynamic and index properties of the overdome materials, the caprock and the salt stock?

5.1.2.3.3. What are the mineralogic variations in the caprock?

5.1.3. What is the present nature of the structural/tectonic system?

For purposes of this section, tectonics will be defined in accordance with the American Geologic Institute Glossary of Geology as ". . . the regional assembling of structural or deformational features, a study of their mutual relations, their origin, and their historical evolution." A structural feature is here defined as a portion of the Earth's crust which is spatially bounded and is uniquely characterized by either its geometric, mechanical or lithologic properties. The boundaries of, and discontinuities within, a structural feature may be considered separate entities, and discussed as structural features in their own right. Penetrative discontinuities or anisotropies, such as rock fabric, foliation, fracture sets and joint sets, will be considered "structural characteristics" of the individual stratigraphic and lithotectonic units. Structural characteristics need to be identified and described where they have an impact on the mechanical behavior of the structural features.

The tectonic system affects design, fluid flow, and radionuclide transport phenomena, and is a major factor in predicting the location and severity of future deformational and disruptive events. Describing the tectonic system begins with establishing the three-dimensional geometry of the lithologic units and identifying major structural features and discontinuities (performance issues 1, 2, 3, 10 and 11). The development of one or more tectonic models provides a framework for understanding the current tectonic system and the active or latent tectonic processes. Once the tectonic processes are understood, their future effect on the geologic setting can be evaluated. Future deformation or disruptive events predicted by the tectonic model will affect design parameters (performance issue 1), retrievability (performance issue 2), and may lead to changes in any or all aspects of the current ground-water flow and radionuclide transport systems (performance issues 3 to 11).

5.1.3.1. <u>What are the structural features ?</u>

Identifying and describing structural features such as folds, faults, domes and basins and igneous intrusions within the geologic setting is the first step toward developing a tectonic framework in which to evaluate ongoing and anticipated disruptive or deformational events, as well as defining the various tectonic provinces. Within the geologic system, currently active structural features will constrain the design of the underground facility (performance issue 1) as well as options for waste retrieval (performance issue 2). The spatial relationships between structural features, and the relationship of these features to the host rock, directly determines flow and transport paths (performance issues 3, 9, 10, and 11).

5.1.3.1.1. <u>What are the structural features related to halokinesis?</u>

5.1.3.1.2. <u>What is the nature and distribution of lineaments and their relation with known structural features?</u>

5.1.3.1.3. <u>What is the relation between overdome faults, caprock faults and anomalous zones or shear zones within the salt stock?</u>

5.1.3.1.4. <u>What is the nature and vertical and lateral extent of the overdome faults?</u>

5.1.3.1.5. What is the nature of saddle faults in the Vacherie Dome geologic system?

5.1.3.2. What are the structural characteristics of the rock units, and how do these characteristics vary ?

Structural characteristics such as foliation, stylolites, flow banding, and jointing are basic to the interpretation of past and present stress fields. These characteristics, along with flow tops and breccia zones in volcanic terrains, also define the dominant planes of structural weakness within a rock unit. These planes of weakness may control the attitudes of future fractures as well as put constraints on repository design and construction. Finally, the structural characteristics within a rock unit are usually mechanically anisotropic, and therefore impact groundwater flow paths directly. Therefore, design (performance issue 1), retrievability (performance issue 2), and groundwater flow within the geologic setting (performance issues 3, 9, 10, and 11) all may utilize this information.

5.1.3.3. What geophysical anomalies exist in the geologic system, and can any structural features, including but not limited to depth to basement, be identified or defined geophysically?

Anomalies in the measured heat flow, gravity, and/or magnetic field need to be accounted for when formulating a model for the deep crustal structure within the geologic setting. The deep structure of the crust is a major feature of any tectonic model which is used to explain the relationships between the structural features. Smaller scale features may support or refute the model as well as indicate areas which may be of significant concern for flow transport modelling. The tectonic model will be used to predict future deformational and disruptive events, design (performance issue 1), retrievability (performance issue 2), future changes in flow paths and rates (performance issues 3, 9, and 10) are all affected. Since a disruptive event could affect the underground facility directly, this information also helps resolve performance issues 4 to 10.

5.1.3.3.1. What is the relation between structural features, lineaments and geophysical anomalies?

5.1.3.4. What is the magnitude, orientation, and spatial variation of the stress field within the geologic system?

Knowledge of the in situ stress is important to determining design criteria and evaluating the potential for breakouts and rock bursts during construction and operation (performance issue 1). The magnitude and orientation of the regional stress field is a primary factor in predicting future disruptive and deformational events and processes. These events may affect groundwater flow paths anywhere within the geologic setting, including the underground facility (performance issues 3 to 10). The orientation of a fault relative to the regional stress field, for instance, is indicative of the possibility for that fault to become reactivated. Furthermore, when the in situ stress ellipse reaches a certain axial ratio (in the neighborhood of 2 to 3) then deformation becomes imminent, independent of the attitude of particular faults. The type of information which might be useful includes: variation of the stress with depth, in situ stress in the host rock and the regional stress field as determined by fault orientations and displacements.

5.1.3.4.1: What is the stress field at the proposed repository level?

5.1.3.4.2. What are the variations from the local stress field within both internal and peripheral anomalous zones?

5.1.3.5. What is the possibility that undetected structural features exist in the geologic system?

It is often possible to predict the existence of faults, folds, or other structural features which lack geomorphic expression. Predictions may be based on geophysical, hydrologic, or borehole evidence, and may be constrained by the tectonic model. The impact of structural features and characteristics on design (performance issue 1), retrievability (performance issue 2), flow regime (performance issues 3 and 11), and radionuclide transport (performance issues 9 and 10) is not diminished by their lack of geomorphic expression. The predicted presence of these structures should also be considered in refining the tectonic model.

5.1.3.5.1. What is the potential for undetected overdome, deep-seated or basement faulting?

5.1.3.6. What are the absolute and relative ages of the structural features?

Determining the relative, and where possible, absolute ages of structural features is a first step toward identifying those structures that may be indicative of current or future tectonic activity within the geologic setting. Tectonic activity affects design and retrievability performance issues (performance issues 1 and 2), as well as all flow and transport models (performance issues 3, 9 and 10). 5.1.3.6.1.

5.1.3.6.1. What is the age of overdome faults, the F-7 Fault and the F-9 Faults?

5.1.3.7. What has been the nature and rate of deformation, whether continuous or disruptive, up to and including the present?

Rates of deformation will be used to predict future changes in the structural features and to evaluate the impact of these changes on the host rock (performance issues 1 to 3 and 9 to 11). High deformation rates may increase the likelihood of disruptive events during the post-closure period.

5.1.3.7.1. What was the rate of diapirism during the Quaternary?

5.1.3.7.2. What was the rate and extent of spine growth during the Quaternary?

5.1.3.8. What regional tectonic models explain the structural features, nature and rates of deformation, and the geometric, mechanical, and age relationships between the structural features?

A regional tectonic model (or models) describes the geometric and mechanical relationship between the observed structural features and links this relationship to past and/or present tectonic processes. Average and maximum rates of deformation calculated for major structural features clearly provide important input into this model. The tectonic model will give geologists a framework within which to evaluate the potential for future deformational and disruptive events. Future deformational and disruptive events directly impact the design of the underground facility (performance issue 1), retrievability (performance issue 2), and anticipated or unanticipated changes in flow paths and rates (performance issues 3, 9 and 10). A disruptive event could also affect the underground facility directly (performance issues 4 to 8). The tectonic model may also lead to the prediction of structural features which lack geomorphic expression, and will thus have an impact in the evaluation of performance issue 11.

5.1.3.8.1. How do the tectonic models explain salt diapirs and their related structural features such as anomalous zones, shear zones, faults, caprock fracturing, and variations in caprock thickness?

5.1.3.8.2. What are the characteristics of the closed topographic depressions over Cypress Creek Dome and adjacent to Richton Dome?

5.1.3.9. What plate tectonic models can account for the current tectonic system?

The plate tectonic model provides a basis for understanding the forces which drive the tectonic processes identified in 5.1.3.1. and 5.1.3.8. A major shift in plate motion would necessarily lead to a re-evaluation of the regional tectonic model, potentially affecting all post-closure performance issues. The plate tectonic model may also account for some large scale structural features, such as major lineaments, which are not easily explained by the regional tectonic model.

5.1.4. What are the nature and rates of seismic activity that have occurred and are occurring in the geologic setting?

Seismic activity is a direct concern in considering the performance of the geologic repository operations area through permanent closure. The nature and magnitude of seismic activity that could affect the geologic repository operations area are important criteria for design. Indirectly seismic activity helps define the tectonic processes operating on the geologic setting and aids in the location of structures along which disruptive movement could occur.

Disruptive movement, in turn, could create, alter or destroy anticipated pathways for radionuclide migration.

In order to more clearly understand the effect of seismicity on the geologic repository operations area in terms of its performance objectives, it is necessary to establish the rates of seismic activity in the geologic setting. Rates derived from human experience and instrumental data are important for evaluating the seismic hazard during the period of operation of the geologic repository operations area. These rates as well as rates derived from geologic evidence will contribute to an evaluation of long term stability.

5.1.4.1. What is the seismic history of the geologic setting?

A data base of historical seismic activity capable of affecting the geologic repository will provide input into design. Information in the data base should aid in the definition of source areas of seismic activity that are both spatially related and characteristically similar.

5.1.4.2. What were the effects of the historic seismic events?

In addition to the location and size of a seismic event, its effect on the natural environment and man-made structures is important information for appraising the degree of attenuation of vibratory ground motion away from the source of the event. It is anticipated that similarly sized seismic events in a locale will yield similar effects.

5.1.4.3. What seismic velocity models have been used for the instrumentally-located earthquakes?

Locations of seismic events based on seismographic data are dependent upon the best model of the crust attainable. The modelled crustal layers and their seismic velocities control not only the quality of the hypocenter location but also the pattern of seismic wave propagation used to define the source mechanism.

5.1.4.4. What is the nature of seismic source areas and seismogenic structures that are of concern to the geologic repository operations area?

With a sufficient quantity of quality seismic information, patterns or clusters of events that can be bounded may emerge. The characteristics of these subsets of seismic events help define tectonic provinces or structures in the geologic setting.

5.1.4.4.1. What is the potential these structural features are seismogenic: A) the Pickens-Gilberton Fault System, B) the Phillips Fault Zone, C) the F-7 Fault and the F-9 Faults ,D) the Mobile Graben E) the Jackson Fault, F) the Maxie-Pistol Ridge Fault G) the Payne Fault?

5.1.4.4.2. <u>What is the southern extent of the New Madrid Fault System and is this system potentially seismogenic?</u>

5.1.4.5. <u>What are the known source mechanisms of earthquakes that have affected the geologic setting?</u>

When sufficient instrumental data exists, focal mechanisms of earthquakes can be determined. These mechanisms can provide valuable information on the nature of regional stresses in the geologic system. The mechanisms also can aid in determining the nature of faulting at depth.

5.1.4.6. <u>What datable evidence of large earthquakes such as surface ruptures or sand boils, exists within the geologic system?</u>

Often, in the source areas of large earthquakes, the normal geomorphic processes are disrupted. In some cases, such as incidences of seasonal cyclic deposition, the timing of these disruptive events can be determined. This information is of particular value in areas where the rate of seismic activity is low and only a short historical record of seismic activity exists.

5.1.4.7. <u>What is the calculated earthquake recurrence rate, determined from the historical record, in the geologic setting?</u>

With a sufficient data base of seismic activity within the geologic setting, it is possible to determine the number of seismic events of a particular size that can be expected to occur within a given span of time and within a given area. This information provides the basis for the extrapolation of the rate of seismic activity to the period of operation of the geologic repository operations area and to the objective of long-term stability.

5.1.4.8. <u>What variations are there in recurrence rates among regional seismic sources and structures?</u>

Within the geologic system there may exist a number of seismogenic structures or zones that exhibit different rates of seismic activity. The activity rates of these various seismic sources and their proximity to the geologic repository operations area provides input to parameters.

5.1.4.9. <u>What are the maximum credible earthquakes that can be attributed to the seismogenic structures or zones expected to affect the geologic system?</u>

Historical evidence, measurable increments of offsets on faults, or relationships of fault length to magnitude, are examples of indicators of the maximum sized earthquakes that can be expected to occur in the geologic system. Each structure can be postulated to have its own maximum credible earthquake. These earthquakes can affect the geologic repository operations area in a variety of ways depending upon the nature of motion at the source and the distance to the area.

5.1.5. What is the nature of natural resources (excluding water) within the geologic setting?

Exploitation of natural resources, such as metallic and nonmetallic mineral deposits and fossil fuels, within or near the geologic repository could have resulted in activities which have created pathways for radionuclide flow and transport. The presence of natural resources may also offer a target of opportunity which may result in either deliberate or inadvertent activities by man that could modify the geologic system. Resolution of this issue therefore could have an impact on the resolution of all performance issues.

5.1.5.1. What are the types, distribution and economic classification of natural resources that could be present within the geologic setting?

In order to determine if the natural resource issue is significant, it is prudent first to determine what type(s) of resources could be present within the geologic system and how these resources are or could be distributed in relation to the geologic repository. In addition , while many types of resources could be present within the geologic setting, only those with a high enough present or potential gross or net worth for humans to attempt to intrude into the repository, either deliberately or inadvertently warrant detailed consideration. This information, therefore, provides the basis for determining the potential for human intrusion through exploration or extraction.

5.1.5.1.1. What is the potential for hydrocarbon resources, lignite or sulfur to be present near the domes?

5.1.5.1.2. What is the potential for the salt within the domes of being or becoming an economic resoure?

5.1.5.1.3. What is the potential of the domes being or becoming an economically viable non-nuclear storage facility?

5.1.5.2. What potential extraction methods could be used to economically recover these resources?

The economic worth of a deposit is not only dependent on the amount of the commodity present but on the cost of development and extraction. For instance, procedures such as underground mining will have a different cost basis than solution mining. This information can then be utilized to evaluate potential human intrusion scenarios, determine which are reasonable, and serve as a basis for determining the significant human induced intrusion scenarios which need to be considered as potentially changing the geologic system.

5.1.5.3. What are the locations and characteristics of boreholes, mines and surface workings ?

To determine the potential pathways for fluid flow, it is necessary to understand where man's past activities may have created pathways as well as the nature of those pathways. In addition, areas that have shown a complex drilling and mining history are by nature those with the highest probability of future activities. Therefore, while this issue is primarily formulated to locate past activities that may have created pathways for radionuclide migration, the information gained provides a relative basis for assessing future intrusion scenarios. This information will aid in resolving performance issues 1, 2, 3, 9, 10 and 11.

5.1.5.3.1. What are the locations and depths of sulfur exploration wells?

5.1.5.3.2. What borehole completion procedures were used?

5.1.5.3.3. What are well production histories?

5.1.5.3.4. What are the locations and characteristics of brine injection or disposal wells and waste storage wells?.

5.1.5.4. What is the nature of fluids that have been injected/withdrawn and the rates at which this has been occurring?

Drilling activities associated with injection may have created potential pathway for fluid flow and transport. In addition, fluid injection can change the stress field and lead to fracturing, creating additional potential pathways for fluid imigration. Injection activities (brine injection for example) can also change the chemistry of the formation waters, affecting characterization activities as well as the repository.

5.1.5.4.1. What is the nature and extent of fluid waste injection wells in the geologic system?

5.1.5.5. Is the geologic system suitable for fluid injection?

The suitability of a formation for injection is a function of its formation properties and the groundwater chemistry. Prior to determining if this human activity is potentially a means of changing the geologic system, it is necessary to determine if stratigraphic units are present that could accept injection, and the types of material that could be reasonably expected to be disposed. In areas remote from population and manufacturing centers, the potential for injection is normally a function of the petroleum resource potential as formation waters from oilfield production normally comprise the largest source of fluid.

5.2. What are the types, probabilities and nature of natural future changes that would modify the nature and rates of geologic processes?

The geologic system is dynamic and interactive. Not only will the geologic system be modified by the presently acting processes described in 5.1., but both the processes and the rates of these processes can change due to action of one natural process on another. For example, climatic changes can alter the geomorphic system by initiating a new glacial age. The resultant changes in the nature and rates of geomorphic processes can also change the local stress field, thereby changing the nature and rates of tectonic processes. The predictive ability of the geologic sciences therefore depends not only on adequate assessment of the present features and processes, but also of the types, probabilities and nature of changes that can modify these rates and processes. A proper assessment of the uncertainty of the projections can then be made.

5.2.1. What are the types, probabilities and nature of future natural changes that would modify the rates and processes of the geomorphic system?

This issue identifies potential natural events that could alter the geomorphic processes, reactivate existing processes and identify the potential recurrence intervals of these processes. The formation or reactivation of these processes anywhere in the geologic setting may significantly modify the geomorphic system. This consideration may require design criteria modification. This issue, therefore, provides information to help resolve performance issues 1 to 3 and 9 to 11.

5.2.1.1. What climatic changes could modify the geomorphic rates and processes ?

The major result of a climatic change would be the initiation of a new ice age, although less noticeable effects on climatic patterns can also severely impact geomorphic rates and processes. Changes in the global climate patterns could modify precipitation patterns, the relationship between precipitation and evaporation, and temperature ranges, as well as produce secondary effects such as flooding or altered rates of erosion. This issue, therefore, provides information for resolution of performance issues 1 to 3 and 8 to 11.

5.2.1.2. What future geomorphic events could alter the geomorphic processes and rates of those processes?

Ongoing geomorphic processes can change the topography of the area, that could in turn affect the geomorphic rates and processes. Mass wasting and slumping can cause stream blockage which can alter present geomporphic processes and their rates. Other processes, such as stream piracy, may have similar effects. This issue therefore provides input to issues 1 to 3 and 8 to 11.

5.2.1.2.1. What is the potential that dissolution-related subsidence would alter stream flow patterns and/or create surface water impoundments?

5.2.1.2.2. What is the potential that glaciation or glacial melting would change erosional processes?

5.2.1.3. What tectonic, seismic, or volcanic processes could alter the geomorphic rates and processes?

Tectonic processes such as uplift and faulting directly affect the rate and type of geomorphic processes by controlling rates of erosion and where the erosion will be focused. The possibility of secondary effects, such as slumping and damming of streams also needs to be evaluated.

5.2.2. <u>What are the types, probabilities and nature of future natural changes that would modify the rates and processes of stratigraphic system?</u>

This issue is concerned with those natural processes, such as volcanism, which could add measurable amounts of material to the stratigraphic setting. Uncertainty bounds should be established for these processes, in addition to projecting how the processes would be manifested. These natural processes might alter existing surface water flow patterns, require changes in design parameters, or affect retrievability options. As such, this issue is relevant to performance issues 1, 2 and 3. Within the Gulf Coast this issues is presently not considered significant.

5.2.3. <u>What future natural changes could modify the tectonic processes or rates of deformation, and what is the probability that these events could occur?</u>

Future natural changes in tectonic processes or events could change the existing groundwater and surface water flow regimes, therefore this information is necessary to resolve performance issues 3, 9, and 10. Deformational creep or the natural formation of new discontinuities can simultaneously create new flow paths and destroy existing ones, and may affect the underground facility (performance issues 4 to 8). The potential for deformational and disruptive events must also be considered when establishing design parameters (performance issue 1) and ascertaining retrievability (performance issue 2).

5.2.3.1. <u>What changes in the tectonic model or tectonic processes can be predicted based on the plate tectonic model?</u>

Changes in plate motions, relative to each other (i.e. cessation of active subduction) or relative to the mantle (i.e. a mantle hot spot or convection cell) can lead to gross changes in the tectonic regime that dominate a geologic setting. Since a change in the governing tectonic model or processes changes all predictions for future deformational or disruptive movement, This information will help resolve performance issues 2 to 11 either directly or indirectly.

5.2.3.2. <u>What types of major climatic change could affect the tectonic processes or the rates of those processes?</u>

Loading changes due to both primary and secondary glacial effects could change rates of deformation and substantially alter the dominant erosional processes. A drop in the mean annual temperature of only a few degrees could initiate a new glacial episode which may affect North America. Even if glacial loading does not directly impact the geologic setting, the subsequent change in sea level could. A major change in the annual precipitation could change rates of erosion/deposition and thus impact any tectonic process which is linked to geomorphic processes. This information will aid in resolving performance issues 3 to 10.

5.2.3.2.1. What is the potential for glacial-induced sea level changes to alter regional tectonic rates?

5.2.3.3. What types of igneous processes or events could lead to changes in the tectonic processes, or the rates of these processes?

Significant volcanic activity would lead to mechanical loading by lava/ash flows, potentially changing the existing rates of deformation. Depletion of a magma chamber within the geologic setting could lead to subsidence, while emplacement of a batholith may lead to doming and/or dike emplacement. Dikes could breach the underground facility and magma movement could induce seismicity and fault movement. The potential for igneous activity should be considered during the design stage, and will have a major impact on retrievability as well.

5.2.4. What are the types, probabilities and nature of future natural changes that could modify seismic processes or the rates of seismic processes?

Since natural seismic activity is a manifestation of tectonic processes, changes in these processes will affect seismic activity. Issues related to changes in tectonic processes are discussed in section 5.2.3 above.

5.3. What are the types, probabilities and nature of human-induced changes (excepting repository-induced changes) that would modify the geologic processes or their rates within the geologic system?

Many human activities have the potential to compromise the geologic repository. The ones considered most siginifcant at this time are are drilling or mining related to natural resource exploitation, flood plain occupation, or flood plain modification. Drilling and mining can open preferred pathways for fluid flow and transport. Flood plain modification or occupation can change the nature and rates of erosion, change the local stress field, and ultimately change the geologic system in which the repository may be located. The description of human induced changes to the geologic system will be most significant for evaluating post-closure performance issues.

5.3.1. What are the types, probabilities and nature of future human-induced changes that could modify the geomorphic processes and their rates?

Human induced events, such as flood plain occupation and modification can have a severe effect on the rates of geomorphic processes by altering stream flow characteristics. Modifications due to mining, fluid injection, or CO2-induced climatic changes, also need to be addressed as they could locally or regionally change present projections. This issue, therefore, addresses the information needs of performance issues 1 to 3 and 8 to 11.

5.3.1.1. What is the potential for CO2-induced climatic changes to modify the geomorphic rates and processes?

The introduction of large amounts of CO2 and associated gasses can cause severe global and local changes in temperature and precipitation patterns. Many projections indicate a doubling of CO2 rates within the period during which the repository is expected to be operational. The effects from this change could significantly modify the present projections of geomorphic processes and their rates.

5.3.1.2. What is the potential for irrigation, flood plain occupation or flood plain modification to modify the geomorphic processes and their rates?

Changes due to changing demographic patterns and land use can cause severe local modifications of the erosional patterns and rates. In addition, the changes induced by changing groundwater flow patterns need to be evaluated as they affect gain/loss patterns of the streams, and thereby change erosional/depositional patterns.

5.3.1.3. What is the potential for exploration, mining, fluid injection or fluid withdrawal to modify the geomorphic processes and their rates?

While this type of activity can modify the surface topography directly, their secondary effects, such as subsidence, can also change the rates and locations of erosional/depositional processes. In addition to the probability of these direct actions changing the geomorphic system, the potential for change in the groundwater flow pattern, and its resultant effect on the geomorphic processes also needs to be evaluated.

5.3.2. What are the types, probabilities and nature of human-induced changes that could modify sedimentary rates and processes?

At this time no human induced changes are considered capable of significantly modifying sedimentary rates and processes.

5.3.3. What are the types, probabilities and nature of future human-induced changes that could modify tectonic processes or the rates of those processes?

Any human activity which modifies the nature or rates of tectonic processes will ultimately lead to changes in the tectonic setting described in 5.1.3. Since tectonic information is required to resolve performance issues either directly or indirectly, human activities which might lead to changes in the tectonic system need to be evaluated. These activities include flood plain modification or irrigation, dam construction, exploration and mining activities, and fluid injection/withdrawal scenarios.

5.3.3.1. <u>What are the types, nature and probability that fluid injection or withdrawal could change the tectonic processes, or the rates of those processes?</u>

Fluid injection or withdrawal associated with the production of hydrocarbons or depletion of water could lead to a change in hydrostatic pressure. The hydrostatic pressure in turn controls the effective tectonic/lithostatic stress regime, and may reactivate existing faults or lead to subsidence of the geologic repository. These problems may occur during operation or after closure.

5.3.3.2. <u>What are the types, nature and probability that irrigation, flood plain occupation or flood plain modification could change tectonic processes, or the rates of those processes?</u>

Dam construction and the associated impoundment of large volumes of water would lead to increased hydrostatic pressure in the host rock, thereby changing the stress field. Irrigation may change the stress field by artificially raising or lowering the water table, and flood plain habitation could change the stress field by changing the lithostatic load on the host rock. These changes in the stress field may subsequently lead to new disruptive events or deformation within the geologic setting. As such, all performance issues, either directly or indirectly require this information to be resolved.

5.3.3.3. <u>What is the probability that exploration or mining activities could modify the tectonic processes, or the rates of those processes?</u>

Mining activities such as the removal of large volumes of rock and the emplacement of tailings piles, may locally perturb the stress field in the geologic setting. This modification of the stress field could in turn produce disruptive or deformational events.

5.3.4. <u>What are the types, probabilities and nature of human-induced changes that could modify the seismic rates and processes?</u>

The seismic history of a geologic setting is the basis upon which projections of expected vibratory ground motions and potential disruptive seismic events is built. It is assumed that historical perturbations of the environment which have induced seismic activity will induce seismic activity under similar circumstances in the future.

5.3.4.1. <u>What is the nature of human activities that could induce seismic activity?</u>

Various types of mining activities and fluid injection/withdrawal activities have been known to induce seismic activity. In addition, impoundment of water in reservoirs has caused moderate to large earthquakes. This information will help resolve performance issues related to repository design.

5.4. What are the types, probabilities and nature of repository-induced changes that would modify the geologic system?

Placing the repository within a geologic setting will physically and chemically stress that setting. These processes will begin during clearing and construction at the surface, which will stress the geomorphic system. Construction and operation will stress the tectonic setting, may affect seismicity and could produce mineral alterations. This information is therefore important to the resolution of all performance issues.

5.4.1. What are the types, probabilities and nature of repository-induced changes that could modify the geomorphic processes and their rates?

The interaction of the repository with its environment will be most noticeable at the surface as the construction will have some effect on surface erosional processes. Additional considerations, however, need to be given to the stress of construction watering/dewatering, the stress of the thermal pulse and the changes introduced to the grouwndwater system and the resultant potential for change in the geomorphic system. This information is needed to resolve performance issues 1 and 2. It is also needed to address performance issues 3, 8, 9, 10 and 11.

5.4.1.1. What is the type, probability and nature of change in geomorphic rates and processes that will directly result from repository characterization, construction, operation and closure?

The repository related activities that will be most noticeable will be the clearing, grading and modification of the surface topography, such as the construction of stock piles and holding dams. These activities will change the surface erosion/depositional patterns, as well as changing surface and groundwater flow patterns. In addition to those which are carried out within the confines of the controlled area, those necessary to operation, such as road and railroad construction, also need to be evaluated.

5.4.1.2. What is the type, probability and nature of change in geomorphic rates and processes that will result from indirect repository-induced changes?

During construction and operation the tectonic and the groundwater system in the location of the repository will be stressed. The potential of these effects to change the geomorphic system needs to be evaluated.

5.4.1.2.1. What is the probability that repository-induced stress will either induce dissolutioning or change the rate at which it is occurring?

5.4.2. What is the type, probability and nature of repository thermal change that could modify mineral stability?

Increased heat flow resulting from waste emplacement may alter mineral phases, and change rock strength and volume within the host rock and adjacent strati-graphic units. As such, the information is needed to evaluate performance issues 1 to 11.

5.4.2.1. What mineralogic changes will occur in the caprock as a function of waste emplacement?

5.4.3. What are the types, probabilities, and nature of repository-induced changes that could modify the tectonic processes, or the rates of those processes?

Any change in the stress field occurring as a result of characterization, construction, operation, or closure may 1) change rates of deformation, 2) lead to the formation of new fracture sets, or 3) induce a disruptive event. Repository design and waste retrievability (performance issues 1 and 2) are most immediately affected if site characterization or repository mining activities induce new fracture sets or induce a disruptive event. The perturbation of the stress field due to the creation of an underground cavity may also affect repository performance in the post-closure period if latent structural features become reactivated or rates of deformation are increased to the point that an unanticipated disruptive event occurs. The creation of new fracture sets will affect the groundwater flow regime in the the geologic setting, and therefore needs to be considered when evaluating performance issues 3, 9 and 10. Knowledge of the possible induction of a disruptive event is also required to resolve performance issues 4 to 8.

5.4.3.1. What is the type, probability and nature of change in tectonic rates and processes resulting from repository-induced thermal-hydrological-mechanical-chemical loading?

High heat flow due to waste emplacement will alter the mechanical properties of the host rock by raising the ambient temperature within the host rock and circulating fluids. This may reduce the long term yield strength of the rock and lead to increased rates of deformation. The mechanical properties of the rocks are fundamental to the design of the repository (performance issue 1), retrievability of the waste (performance issue 2), and future groundwater flow regimes within the geologic setting (performance issues 3, 9, and 10). The thermal expansion of the circulating groundwater may significantly increase the hydrostatic pressure within the geologic setting, possibly leading to a disruptive event (performance issues 4 to 8). There is also the potential that thermal expansion of groundwater will cause overpressuring in some units, and perhaps initiate tectonic activity. This possibility should be evaluated in conjunction with known porosities and permeabilities of the stratigraphic units.

5.4.3.1.1. What is the potential for repository loading to alter diapiric rates?

5.4.3.2. What is the type, probability and nature of change in the tectonic rates and processes induced by site characterization and repository construction?

Exploratory drilling, seismic surveys, and exploratory shaft and tunnel construction may impact tectonic rates and processes by inducing deformation or disruptive movement. The primary issues which will need this information for resolution are those related to design and retrievability (performance issues 1 and 2), however, this information may also be needed to resolve performance issue 11 if a new fracture set is formed by blasting or mining activities.

5.4.4. What are the types, probabilities and nature of repository-induced changes that could modify the seismic rates and processes?

The seismic history of a geologic setting is the basis upon which projections of expected vibratory ground motions and potential disruptive seismic events is built. It is assumed that historical perturbations of the environment that have induced seismic activity will likewise induce seismic activity in similar circumstances in the future. It is further assumed that thermal characteristics of the repository may affect the local seismicity in addition to the effects of the mining activity.

5.5. What are the future effects on the geologic system resulting from natural changes?

Prediction of the future effects of geologic processes is not an exact science at the present time. Not only is there uncertainty associated with determining if the present rates and processes are adequately understood, there is uncertainty associated with determining if the rates and processes can change and how they can change. Because the uncertainty bounds on the processes are relatively large, it is necessary that the changes to the geologic setting that can be projected based on present conditions be assessed as well as making an assessment of how these rates and processes can change (section 5.2) and the resultant effect of these changes. As resolution of this issue affects flow/transport, design and all related performance objectives, this issues is responsive to the information needs necessary to resolve the related performance issues.

5.5.1. What are the future effects on the geologic system resulting from natural changes in the geomorphic system?

As a result of geomorphic processes like erosion and mass wasting, modification of the geologic system will occur which must be accommodated by proper design. A clear distinction must be made between those processes that significantly affect the geologic setting, and therefore require additional investigation, and processes which have little or no effect.

5.5.1.1. What are the future effects on the geologic system if the geomorphic rates and processes remain constant?

Geology is a dynamic system in which the rates and processes are continually changing. It is first necessary to determine the impact of geomorphic processes on the geologic system under expected conditions based on present rates and processes to determine if these expected effects are significant. This baseline provides a standard from which potential variations to the system can be judged.

5.5.1.2. What will be the effects on the geologic system if the geomorphic rates and processes are modified by natural induced activities?

The effects of natural events and processes which are capable of changing the geomorphic system, as described in 5.2.1., should be evaluated. The initiation of a new ice age is the most obvious concern, however, any process which can significantly change the rates and processes of the geomorphic system can have an effect on the geologic repository and therefore on meeting the performance issues. This issue is of primary concern during the post-closure period.

5.5.2. What are the future effects on the geologic system resulting from natural changes to the sedimentary processes?

The potential effects on the stratigraphic units resulting from natural phenomena might include the projected sedimentary processes and rates which could change the vertical extent, lateral extent, physical, chemical or index properties of the units. Since these changes may alter design considerations, may alter groundwater flow patterns, or may affect retrievability options; performance issues 1 to 11 may require this information.

5.5.2.1. What are the future effects on the geologic system if volcanism occurs?

The most significant effects of volcanic activity on the stratigraphic setting are those which alter the composition and physical properties of the geologic system. Extrusive events and their associated flows and debris falls can alter the loading capacity, ground water recharge or discharge rates, moisture retention capacity or mineralogy and petrology of surficial units (performance issues 3 to 11). Intrusive volcanic events can initiate secondary effects such as additional thermal loading of the host rock or adjacent units. Such events may also require special design considerations to mitigate their effects (performance issues 1 and 2). The potential for volcanic activity will need to be considered in light of the repository location, which will determine the impact of this issue. Based on present knowledge, secondary volcanic effects such as ash falls from distant events might occur, however, this issue is not considered significant within the Gulf Coast.

5.5.3. What are the future effects on the geologic system resulting from natural changes to the tectonic processes and the rates of those processes?

Natural changes to the tectonic processes and rates of those processes can impact flow and transport models for the geologic setting, and may lead to the deformation or disruption of the underground facility. Since design parameters and retrievability options are also affected, this issue provides information to aid in the resolution of all performance issues.

5.5.3.1. How would the geologic system change if the tectonic processes and rates of deformation remain the same?

The geologic system, will continue to be modified by the active tectonic processes at their present rates even without future changes to these processes or rates. It is critical to the evaluation of all performance issues that the no-change-in-rates-or-processes scenario be understood. This scenario should include projecting the development of existing faults, folds, domes, basins, and other structural features through the post-closure period. This information is needed for the resolution of all performance issues.

5.5.3.2. How would the geologic system change as a result of a change in plate tectonic processes?

Abrupt changes in the direction or speed of plate motions (or other primary driving forces) have the potential to affect the geologic setting within the post-closure period. If the primary deformational forces within the crust change, then the tectonic model would have to be modified accordingly. The result would modify all projections regarding the future tectonic system.

5.5.3.3. How would the geologic system change as a result of a major climatic shift affecting the tectonic processes or rates of deformation?

A major increase or decrease in annual precipitation could raise or lower the groundwater table and thereby change the hydrostatic component of the stress field. A change in mean annual temperature of only a few degrees could lead to continental glaciation with significant mechanical loading in proximal areas and significant sea level changes in more distal areas. Where this issue applies, the lithostatic and/or hydrostatic components of the stress field may be strongly affected. Since deformational or disruptive events could be induced by any perturbation in the stress field, performance issues 3 to 10 may be affected.

5.5.3.4. How would the geologic system change as a result of geomorphic processes or events affecting the tectonic processes or rates of deformation?

Any changes in the stress field could induce deformational or disruptive events, while changes in rates of uplift/subsidence could lead to premature exhumation of the waste package. Geomorphic processes leading to the damming of streams or rivers could change the hydrostatic stress within the geologic setting. Changes in drainage patterns due to catastrophic events could also lead to greatly increased rates of erosion or deposition, and thereby change the lithostatic stress locally within the geologic setting. In many cases rates of subsidence/uplift are governed by sedimentary loading/unloading.

5.5.3.5. How would the geologic system change as a result of igneous processes or events affecting the tectonic system?

Magma movement within or near the geologic setting could induce deformational or disruptive events. Existing fractures may act as conduits for dike emplacement, or new fractures may be formed. Dikes or volcanic vents may breach the underground facility, or the surface facility could be covered by a lava flow or ash fall. Heat flow could be elevated to critical levels by emplacement of a dike or stock within the geologic setting, and this could in turn affect the groundwater flow regime (performance issues 3,9,10 and 11).

5.5.4. What are the future effects of seismic activity within the geologic system?

Knowledge of appropriate postulated seismic events within the geologic setting, along with a knowledge of areas subject to undesirable responses to these events, can provide the information required to accommodate or mitigate their effects. Most seismic activity can be accomodated by utilizing appropriate design parameters. Certain effects, however, such as ground rupture, liquefaction and landsliding may require mitigation by avoidance.

5.5.4.1. What is the maximum expected ground motion in rock at the geologic repository operations area resulting from the maximum credible earthquakes, examined as a function of depth to at least the depth of the underground facility?

The maximum peak or sustained maximum ground accelerations and velocities are important parameters in the design of the geologic repository operations area. The filtration and attentuation effects of the rock on the seismic waves are significant factors affecting the ground motion at the geologic repository operations area, not only at the surface but also within the underground facility and along connecting tunnels and shafts.

5.5.4.2. What are the postulated catastrophic coseismic events, such as landslides, liquefaction or ground rupture that could affect the geologic repository?

A geologic repository operations area will not be sited on an active fault; however, certain catastrophic events associated with major events within the geologic setting could permanently affect the geomorphologic and hydrologic processes significant to the containment of radioactive waste.

5.5.4.2.1. Are the sediments over Cypress Creek Dome subject to liquifaction?

5.5.4.3. What are the postulated effects on the seismic system that would result from a change in the tectonic rates and process?

Since natural seismic activity is a manifestation of the tectonic processes, changes in these processes will affect the rates and processes of the seismic system. Issues related to changes in tectonic processes are discussed in Section 5.2.3 above.

5.6. What are the future effects on geology resulting from human-induced changes within the geologic setting?

Human activities have the potential to significantly modify the geologic system and conditions such that rates of erosion and deposition can be changed, flow paths created and/or altered, and local stress fields can be changed. If the information presented in response to issue 5.3. indicated that there is a significant possibility of these activities occurring, and if their occurrence is close enough to the repository to warrant concern, then an evaluation of the potential effects is required. This issue is potentially responsive to the information needs of all performance issues.

5.6.1. What are the future effects on the geologic system resulting from human-induced changes to the geomorphic system?

Most human activities will result in changing rates of erosion. The more difficult series to evaluate are the secondary and tertiary effects of changing groundwater flow systems and the resultant effect on the geomorphic system. Changes in rates of erosion should be addressed in design. The changes due to changing groundwater system could have a long term effect due to changing the rates of geomorphic processes as well as where it will be focused.

5.6.1.1. What are the effects on the geomorphic system resulting from increase in the $CO_2$ levels in the atmosphere?

Large changes in atmospheric $CO_2$ level as well as other gases are projected to occur within the operational life of the repository. The effects of these changes on the geomorphic system may significantly modify long term projections.

5.6.1.2. What other effects on the geologic system due to human-induced changes to the geomorphic processes can be projected?

Alteration of geomorphic processes due to activities such as flood plain occupation and modifi-cation, could affect erosional or depositional patterns, surface water and groundwater flow and recharge rates, and thereby produce both primary and secondary changes to the geomorphic system. This information will aid in developing design criteria and recognition of a potential route for radio nuclide release.

5.6.2. What are the future effects on the geologic system resulting from human-induced changes to the stratigraphic setting?

Although no human activity can be envisioned that could change sedimentary processes and rates (see issue 5.3.2), human activity can have an effect upon the existing stratigraphic setting. Exploratory drilling and boring activity as well as mining will create cavities of various dimensions which, if sufficiently close to the host rock, can induce fracturing and change the lithostatic pressure on the geologic repository. As such, this issue provide information potentially significant to all performance issues.

5.6.3. What are the future effects on the geologic system resulting from human-induced changes to the tectonic processes and rates of those processes?

The primary effect of human induced changes will be to alter the ambient stress field within the geologic setting. Since the stress field controls all tectonic processes and their rates, all performance issues may require this information, either directly or indirectly.

5.6.3.1. What are the future effects on the geologic system resulting from changed tectonic processes due to fluid injection or withdrawal?

Fluid injection or withdrawal associated with the extraction of hydrocarbons or use of water could lead to a change in hydrostatic pressure. The hydrostatic pressure in turn controls the effective tectonic/lithostatic stress regime, and may reactivate existing faults or lead to subsidence of the geologic repository.

5.6.3.2. What are the future effects on the geologic system from flood plain occupation/modification or irrigation modifying the tectonic system?

Dam-construction and the associated impoundment of large volumes of water would lead to an increased hydrostatic pressure and thereby modify the stress regime within the geologic setting. Irrigation may lead to the artificial raising/lowering of the water table and subsequently to a change in the hydrostatic stress. Flood plain occupation could lead to a change in the lithostatic component of the stress field as well as altering the hydrostatic stress through various uses of ground and surface water. Any change in the stress field has the potential to reactivate existing structural features, initiate new styles of deformation, and possibly interfere with the repository during operation as well as in the post-closure period.

5.6.3.3. <u>What are the future effects on the geologic system resulting from exploration or mining activities modifying the tectonic system?</u>

Blasting and associated mining activities may induce fractures in the surrounding rock units. The relationship between the induced fractures and existing fracture sets needs to be understood. This modification of the stress field would affect repository design, waste retrievability, and flow and transport issues, as does any change in the ambient stress field. The removal of large volumes of rock, and the associated emplacement of tailings piles, could locally perturb the stress field.

5.6.4. <u>What is the ground motion associated with human-induced seismicity, as a function of depth, at least to the depth of the underground facility?</u>

Spectral characteristics resulting from induced seismic events can vary significantly from characteristics of natural events in the geologic setting. Induced seismic events may occur in localities much closer to the geologic repository operations area than is the case for natural events.

5.7. <u>What are the future effects on the geologic system resulting from repository-induced changes?</u>

Prediction of the effects of the repository and on the geologic system will help determine the final design and flow, transport, and waste package models, and therefore help determine how the system will ultimately respond. This issue therefore provides information that may be necessary to resolve all performance issues.

5.7.1. <u>What are the future effects on the geologic system resulting from repository-induced changes to the geomorphic system?</u>

As a result of repository induced events (i.e., construction of a repository and roads, construction of containment areas for drilling fluids and extracted materials, and an increased thermal gradient) significant modification of the geomorphic system could occur. In addition to the primary effect, such as construction activities modifying the erosional patterns and rates, secondary geomorphic effects resulting from changes to the tectonic and groundwater system also need to evaluated.

5.7.1.1. <u>What are the direct effects on the geomorphic system resulting from repository characterization, construction, operation and closure?</u>

Altered geomorphic processes due to construction of the repository and roads, construction of containment areas for water, extracted materials, or drilling fluid could affect base-level or the mass wasting rate. Predicted effects will aid in identifying the potential changes in erosional or depositional patterns, surface and groundwater flow rates, and recharge rates. Understanding these effects will clarify design criteria, retrievability and radionuclide transport systems.

5.7.1.2. What are the predicted secondary effects on the geomorphic system due to induced stress on the tectonic and hydrologic system?

As the geomorphic system is a reflection of all other ongoing systems, changes in the stress field, both mechanically and thermally induced, and changes in the groundwater and surface water flow paths due to the repository, could cause changed geomorphic rates and processes. The results of these changes need to be evaluated.

5.7.2. What are the future significant effects on mineral stability resulting from repository-related thermal loading?

Alterations to mineral assemblages resulting from thermal loading may alter rock volume, porosity or other physical and chemical properties. Furthermore, the extent of these alterations may change through the operational repository life. In that groundwater modeling and design considerations are dependent upon these effects, the information is necessary to resolve performance issues 1 to 11.

5.7.3. What are the future effects on the geologic system resulting from repository induced changes to the tectonic system?

Repository construction and waste emplacement may have both short term and long term effects on the geologic system. Blasting and mining activities may induce the formation of new fractures (issue 1), and these may in turn interact with existing fracture sets to change the scenario for disruptive or deformational movement (issues 2 to 10). The thermal effect of the waste on the geologic system will largely concern the long term behavior of the rock within the present or future stress field. If the material properties of the rock are substantially affected, then deformational and disruptive event scenarios will have to account for this variation. Thermal expansion of circulating ground water could also lead to significant changes in the stress field, changing the effective lithostatic load and perhaps facilitating movement on existing fractures.

5.7.3.1. What are the future effects on the geologic system resulting from waste-related thermal-mechanical-chemical loading?

High temperatures and high heat flow may change the long term mechanical behavior of the rock, potentially increasing the probability of deformational and disruptive events. The thermal expansion of groundwater may lead to increased hydrostatic pressures and possibly overpressuring of particular lithologic units. If overpressuring occurs, the likelihood of a deformational or disruptive event is greatly increased. To the extent that a disruptive event would impact every aspect of design, retrievability, flow and transport, this information is needed to resolve all performance issues.

5.7.3.2. <u>What are the future effects on the geologic system resulting from site characterization and construction activities?</u>

Exploratory drilling and exploratory shaft and tunnel construction can affect the geologic system by inducing fracturing locally and possibly inducing a disruptive event. The relationship between natural and mining induced fractures needs to be clearly understood for characterization purposes. The primary issues which need this information for resolution are performance issues 1 and 2.

5.7.4. <u>What is the ground motion associated with repository-induced seismicity, as a function of depth, at least to the depth of the underground facility?</u>

Spectral characteristics resulting from induced seismic events can vary significantly from characteristics of natural events in the geologic setting. Induced seismic events within the repository may require special considerations in design.